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ECONOMICS OF CONSOLIDATING SEWAGE TREATMENT PLANTS BY MEANS OF INTERCEPOTR SEWERS AND FORCE MAINS

Robert Smith, et al

Environmental Protection Agency
Cincinnati, Ohio

April 1971

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ECONOMICS OF CONSOLIDATING SEWAGE TREATMENT PLANTS BY MEANS OF INTERCEPTOR SEWERS AND FORCE MAINS

by
Robert Smith
Richard G. Eilers

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ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Monitoring
Advanced Waste Treatment Research Laboratory
Cincinnati, Ohio

April 1971

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UNITED STATES GOVERNMENT

Memorandum

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TO : Dr. W. N. Fitch, Systems Analysis of Economics Branch

DATE: January 22, 1971

FROM : Robert Smith, Chief
Treatment Optimization Research Program, AWTRL

SUBJECT: The Cost Breakeven Point for Consolidating Sewage Treatment Plants by Means of Pipelines

This memorandum is in response to a request by Mr. C. L. Swanson to make some preliminary computations showing the conditions under which consolidation of sewage treatment plants by pipe transmission is economically feasible.

To make such a computation we must first have the cost of building and operating secondary plants and also the cost of building and operating pipelines. Our best estimate of the cost of owning and operating complete secondary plants utilizing the activated sludge process is shown in Figure 1.

The cost of pipelines will depend upon the amount of flow transmitted, the length of the pipe and the difference in elevation between the two plants to be joined by the pipeline. The cost of laying the pipeline is not sensitive to the kind of material used. For example, no significant difference appears to exist between concrete pipe and cast iron pipe. The cost per mile of laying the pipe depends only on the inside diameter of the pipe. The relationship used for construction cost of pipelines is given in Table I. The life of a pipeline is taken as 50 years and the rate of interest as 6%.

If the effluent end of the pipe is above the influent end or if the available slope is not enough to maintain a 2 ft/sec velocity for self cleaning a pumping station must be provided. The construction cost of pumping stations as a function of theflow is shown in Table I. Amortization cost for pumping stations was based on 6% and 25 years.

Operation and maintenance cost for the pumping station is shown as a function of the flow in the Table I. The cost of maintaining the pipeline is taken as $40/mile/yr. This cost is insignificant compared to other costs.

Electrical power for pumping the sewage from the community being served to the plant depends on the frictional loss in the pipe as well as the difference in elevation between the two plants. In

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this study where force mains are considered the difference in elevation is taken as five feet per mile. The frictional drop was calculated using the Hazen-Williams formula and a roughness factor of 100.

Where gravity sewers are considered it is assumed that the plant receiving the flow is lower in elevation than the community being served and that the gravity sewer is sized to give 3 ft/sec flow velocity when running full.

In designing force mains the economical pipe diameter should be used. This is the diameter which minimizes the sum of the cost of frictional power and the debt service for the pipe. Linaweaver and Clark writing in the AWWA Journal of December, 1964 found the relationship between flow and economical diameter to be as follows.

$$\text{Economical Dia., inches} = 8.55\ Q^{0.463}$$

where Q = design flow, mgd.

This relationship was used here to size force mains.

The size relationship for both gravity sewers and force mains are shown in Figure 2. The Ten States Standards requires interceptor sewers to be sized to carry 3.5 times the design flow for the plant. This factor was used here for sizing both the pipelines and the pumping stations.

The only significant cost associated with gravity sewers is the amortization cost. This is shown as cents/1000 gal/mile versus the average flow transmitted in Figure 3. At 20 mgd the amortization cost, not shown on the graph, is 0.6907 cents/1000 gal/mile. This corresponds to an 82 inch diameter pipe.

For force mains the amortization cost, the pumping power, and the maintenance are proportional to length. The amortization and operation and maintenance cost for pumping stations are a function of flow only. These costs are shown in Figure 4. It should be noted that sizing the pipe and the pumping station for 3.5 times the average flow makes transmission of wastewater particularly expensive. If a reservoir or holding basin could be provided the cost of the pipeline and pumping station could be significantly reduced.

The economic feasibility of consolidation of plants will depend as much on the existing situation as on the expense of the pipeline. For example, consider two communities, A and B, which both have a need for sewage treatment by means of the conventional activated sludge process and associated processes. As a start we can consider three hypothetical cases which might arise.

Case I. Neither community has an existing sewage treatment plant.

Case II. One community, A, owns and operates an activated sludge plant with sufficient excess capacity to serve the second community, B, which has a need for treatment but does not own a plant.

Case III. One community, A, owns and operates an activated sludge plant with no excess capacity. Community B has no plant but community A offers to accept the wastewater of community B if additional capacity is provided at the plant of community A.

First, consider Case I where each community needs a one mgd plant. The two alternatives are; first, for each community to build and operate its own plant and second, for community A to build a two mgd plant and treat the sewage from both communities. Using Figure 1. we see that if both build plants the cost will be 25.2 cents/Kgal. If community builds a two mgd plant the cost will be 22 cents/Kgal and the pipeline will cost 1.71 cents/Kgal/mile. To find the breakeven point we can equate the total daily cost of the two alternatives and solve for the length of the pipeline at the breakeven point as follows.

$$\underbrace{(25.5)1000 + (25.5)1000}_{\text{both build plants}} = \underbrace{(22)2000 + 1.71(L)1000}_{\text{one plant and pipeline}}$$

Solving this equation for the breakeven length of pipeline (L) we find that L equals 4.1 miles. If we make the pipeline longer than 4.1 miles the cost of the second alternative will exceed the cost of building two separate plants. If we make the pipeline shorter than 4.1 miles the total cost will be less than the cost of two separate plants. Thus, in this simple example, the decision is based solely on whether the two communities are more or less than 4.1 miles apart. The breakeven distances have been worked out for other size plants and combinations of different sizes. The results are shown in Figure 5.

Consider Case II in which community A has unused excess capacity. It can be assumed here that community A is currently paying the debt service on the existing plant with excess capacity but paying operation and maintenance cost based on only the flow actually treated. For example, again assume that community A has a plant capable of treating 2 mgd but the stream entering the plant from community A is only one mgd. Community B needs sewage treatment for one mgd and must decide whether to build its own plant or build a pipeline to the plant of community A.

If both communities operate plants the cost to community A will be $10.9 + 2(12.6) = 36.1$ cents/Kgal. If the sewage from both communities is treated in community A's plant the cost will be 22 cents/Kgal plus the cost of the pipeline. Equating these two possibilities gives the following equation.

$$\underbrace{(36.1)1000 + (25.5)1000}_{\text{both build plants}} = \underbrace{(22)2000 + 1.71(L)1000}_{\text{one plant and one pipeline}}$$

Solving this equation for the breakeven pipeline length, L. gives 10.3 miles. If the communities are less than 10.3 miles apart they should consolidate. If they are more than 10.3 miles apart the most economic solution is to build separate plants.

Using this Case II example we can now show the effect of owning and operating a pumping station. Assume that sewage must be pumped from community B to community A and the difference in elevation is five feet per mile. The cost of owning and operating a one mgd pump station with 3.5 mgd peak capacity is 8.3 cents/Kgal. The cost of owning and operating the pipeline, including electrical power, is 1.7 cents/Kgal/mile. The equation for finding the breakeven pipe length is written as follows.

$$\underbrace{(36.1)1000 + (25.5)1000}_{\text{both build plants}} = \underbrace{(22)2000 + (8.3)1000 + 1.7(L)1000}_{\text{one plant and one pipeline}}$$

Solving this equation for L we find 5.47 miles as the breakeven distance. Additional examples are presented in Figure 6.

From these few simple examples it can be seen that the minimum cost solution for most problems of plant consolidation is easily found. It is clear that whether or not pumping is required is an important factor. Whether or not excess capacity exists in the community A plant is an important factor. In the most optimistic case the length of pipeline which is economically feasible seldom exceeds about ten miles.

TABLE I

1. Construction Cost of Pipelines:

$$\text{Construction Cost, } \$ = 1524.7(ID + 2.0436)^{1.37949}$$

ID = inside diameter of pipe, inches

2. Construction Cost for Pumping Stations:

$$\text{Construction Cost, } \$ = 76{,}300\ Q^{.7682}$$

Q = average flow, mgd

3. Operation and Maintenance Cost for Pumping Stations:

$$\text{Cents/1000 gal} = 1.59\ Q^{-.263}$$

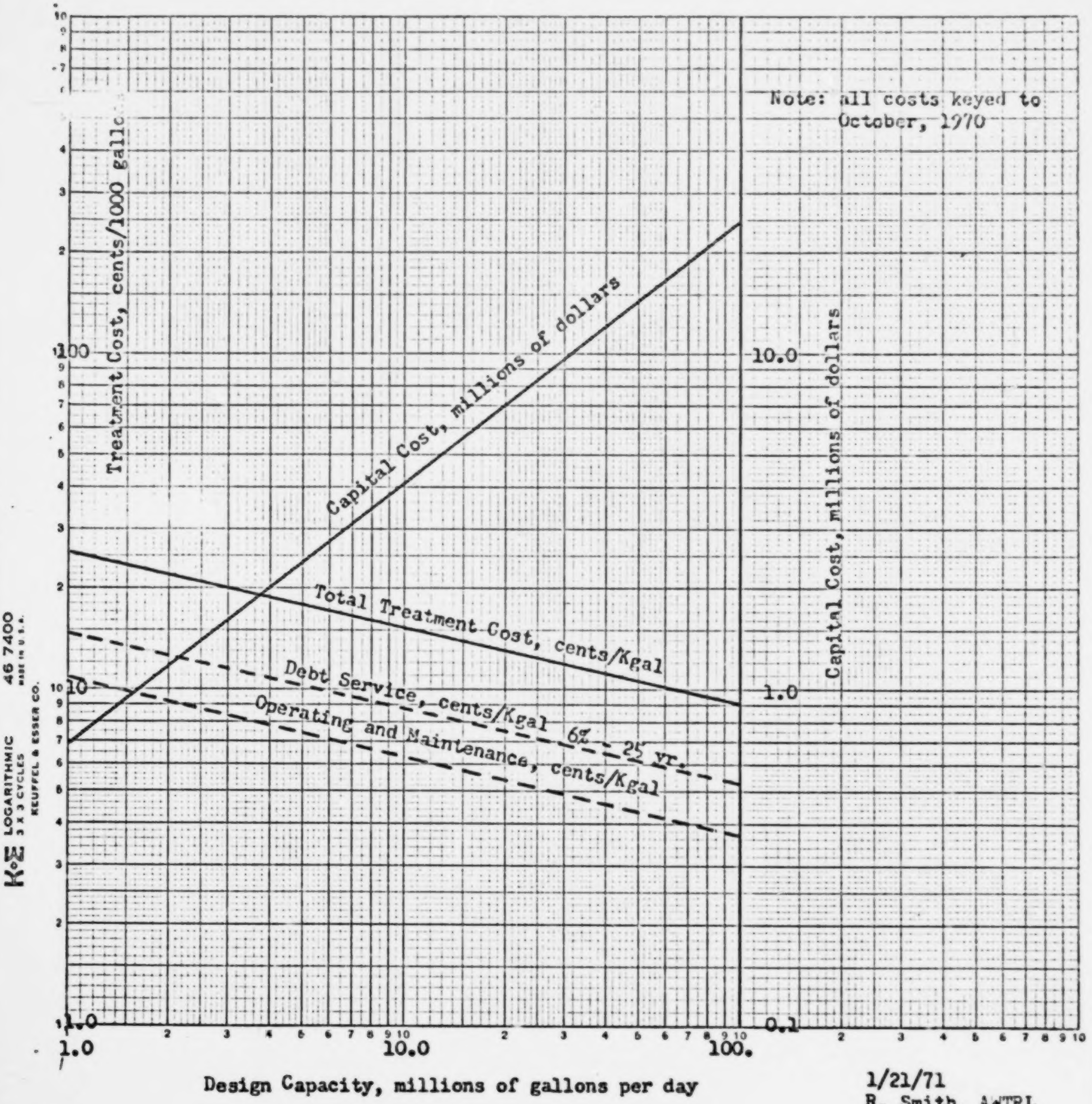
4. Maintenance Cost for Pipelines = \$40/mile/year

5. Hydraulic Efficiency of Pump = 60%

6. Electrical Efficiency of Motor = 85%

Note: All costs keyed to October, 1970

ACTIVATED SLUDGE PLANTS Figure 1



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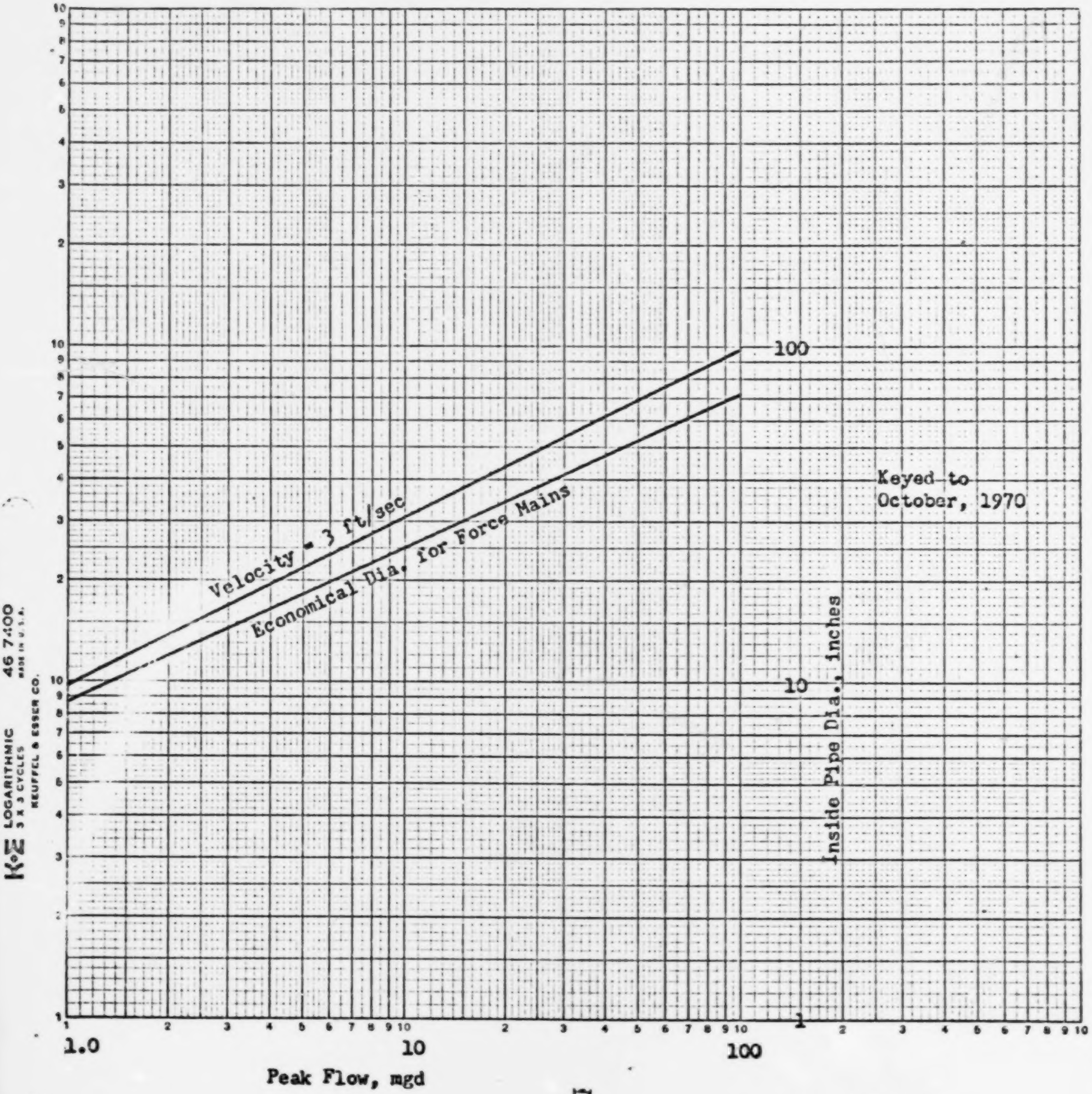
PIPE DIAMETER versus PEAK VOLUME FLOW Figure 2



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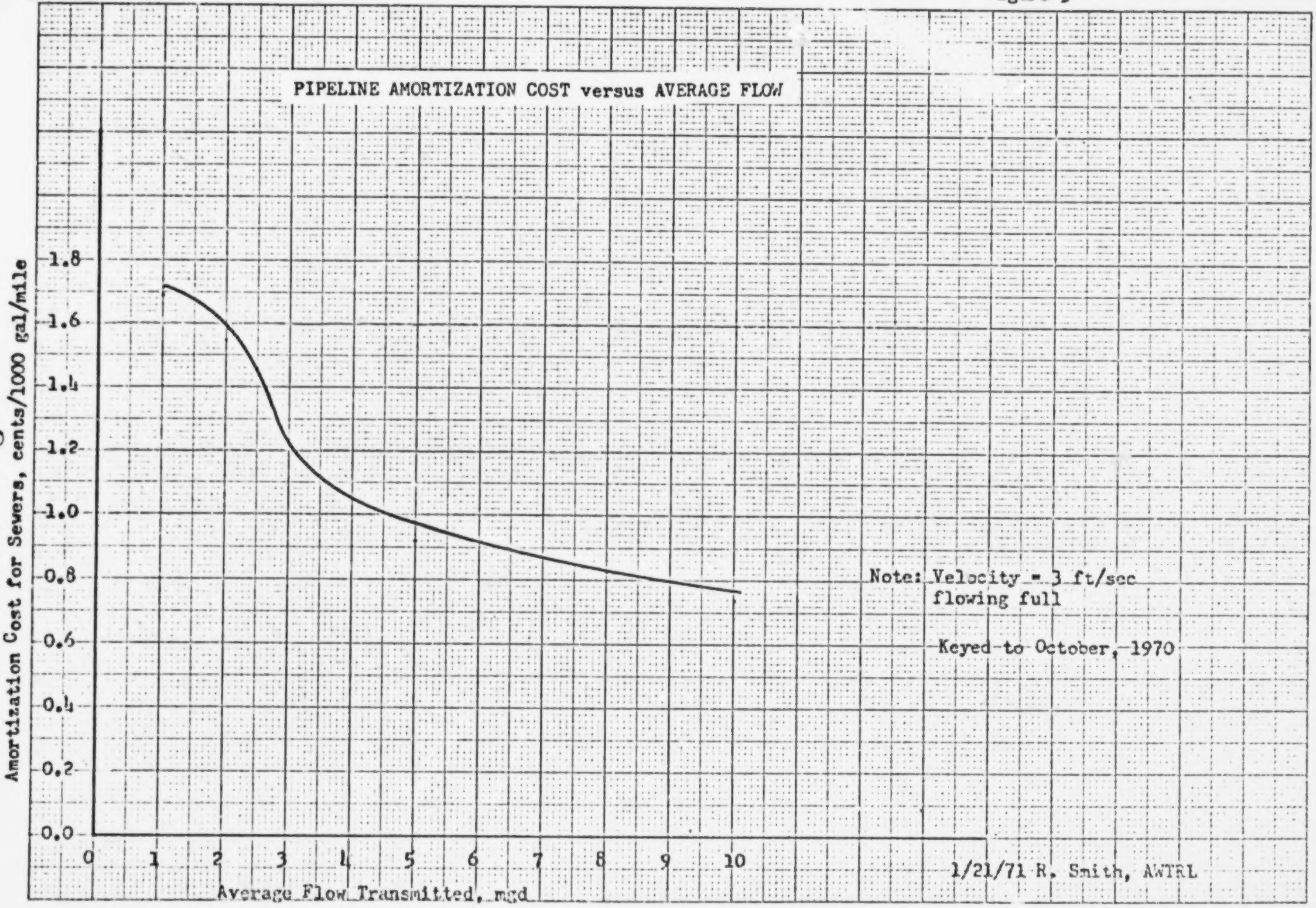
AWTRL

K&E 10 X 10 TO ½ INCH 46 1320
7 X 10 INCHES
KEUFFEL & ESSER CO.

Figure 3



PIPELINE AMORTIZATION COST versus AVERAGE FLOW

Note: Velocity = 3 ft/sec
flowing full

Keyed to October, 1970

1/21/71 R. Smith, AWTRL

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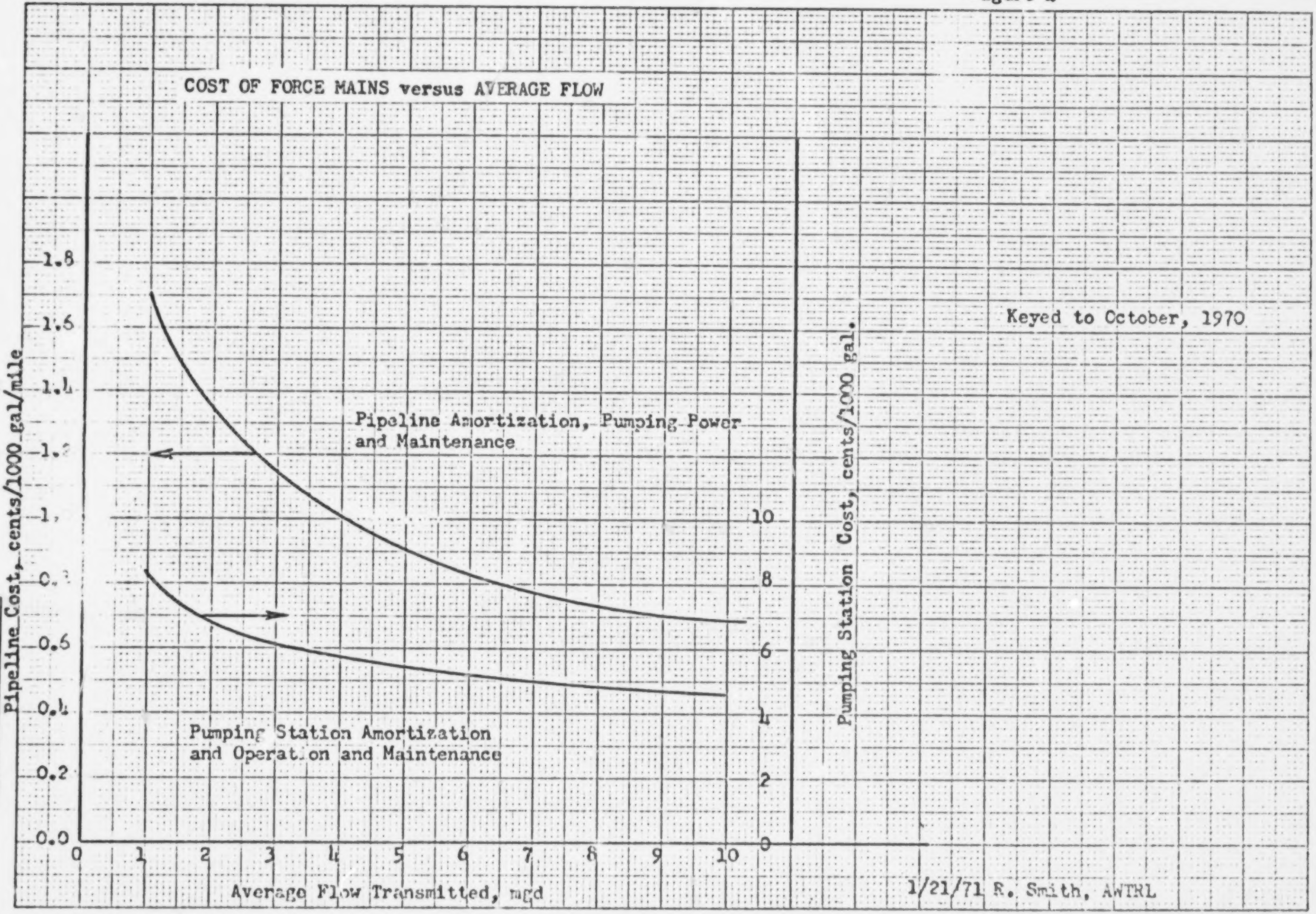
K•E 10 X 10 TO ½ INCH 46 1320
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

Figure 4



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BREAKEVEN DISTANCE IN MILES

	Community B						
Community A	1	2	5	10	20	40	60mgd
1	4.1						
2		4.1					
5			5.3				
10	7.1			5.7			
20					5.5		
40						4.6	
60	8.8			9.3			4.1

Case I - gravity sewers

	Community B						
Community A	1	2	5	10	20	40	60 mgd
1	N						
2		N					
5			N				
10	2.3			N			
20					N		
40						N	
60	4.0			N			N

Case I - force mains

Note: N means economic solution is to build two plants

Figure 5

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AWTRL

BREAKEVEN DISTANCE IN MILES

	Community B						
Community A	1	2	5	10	20	40	60 mgd
1	10.3						
2		9.8					
5			12.8				
10	11.2			14.0			
20					13.3		
40						11.4	
60	12.5			15.2			10.3

Case II - gravity sewers

	Community B						
Community A	1	2	5	10	20	40	60 mgd
1	5.5						
2		6.7					
5			7.8				
10	6.4			9.0			
20					7.5		
40						5.7	
60	7.7			10.3			4.5

Case II - force mains

Figure 6 1/22/71
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UNITED STATES GOVERNMENT

Memorandum

MAGNAFAXED TO DR. FITCH, WASHINGTON - 2/3/71

ADVANCED WASTE TREATMENT RESEARCH LABORATORY

TO : R. Smith, Chief
Treatment Optimization Research Program, AWTRL

DATE: February 3, 1971

THRU : F. M. Middleton, Director of Research, AWTRL FMM

FROM : C. L. Swanson
Contracts & Grants Activities, AWTRL

SUBJECT: Cost-Effectiveness Task Force - Economics of Consolidating Sewage Treatment Plants by Means of Interceptor Sewers and Force Mains

Your assistance is requested by the Task Force to develop procedures for evaluating the cost-effectiveness of applications for construction grants, basin plans, and metropolitan/regional plans. This effort should be directed toward development of cost data and procedures for determining the relative economics of use of interceptor sewers and relatively large treatment plants versus a series of smaller treatment plants.

A large number of applications for construction grants were received at the end of December, 1970. Regulations require that applications submitted after 1970 be accompanied by interim basin and metropolitan/regional plans. Detailed plans will be required after July 1, 1973.

The initial objective of the Task Force is to develop procedures for use by WQO Regional staffs to evaluate applications submitted during the amnesty period. This effort should be completed as soon as possible during the next 2 to 3 weeks. A second objective is to develop more detailed methodology to be used by State personnel and Regional staff after April 1, 1971. The latter information may also be supplied to consulting engineers, cities, and sanitary districts.

Your memorandum of January 22, 1971 to Dr. Fitch provides a good basis for further studies. At the Task Force meeting on February 1, the following suggestions were made for additional work to accomplish the initial objective:

1. Cost curve for activated sludge plants

It would be preferable to show a general cost curve for secondary treatment or a separate cost for trickling filter plants. As we have discussed, it is unlikely that a straight line on log-log graph paper adequately defines costs for plants larger than 30 to 50 mgd. If possible, preliminary data from the Black & Veatch study should be used to prepare a revised cost relationship.

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2. Cost for force mains

Pumping stations are included in the cost comparisons for force mains in your initial writeup. It is not clear if an allowance has been made in treatment plant costs, since raw sewage pumping would not be required for a portion of total plant flow.

3. Advanced waste treatment

The cost for AWT should also be considered, as follows:

a. Secondary treatment and 80 to 90 percent phosphorus removal - chemical treatment of raw sewage or mineral addition to aerator.

b. Tertiary clarification and filtration to provide for phosphorus removal and additional removal of BOD and suspended solids.

c. Tertiary clarification for phosphorus removal, filtration, and granular carbon adsorption.

4. Graphical rather than mathematical solutions are preferred for determining economical force main sizes, etc.

5. Costs for interceptors and force mains versus size should also be included.

6. Charts showing breakeven distance for consolidating plants

This is considered to be an excellent method for comparative purposes and should be expanded to allow for the following:

a. Upstream city is situated on a small stream and requires advanced waste treatment - Downstream city requires only secondary treatment.

b. Both cities require AWT.

Some type of standard form or format for use by Regional staffs in making "rough" calculations would be desirable, including examples for more complex situations such as consolidation of 3 or more plants.

Please consider the above comments only as a guide for additional work. The Task Force solicits your input on accomplishing the basic objective of providing Regional staffs with a tool to determine cost effectiveness of projects.

The scope of work to develop a more detailed methodology can best be defined after initial guidelines are completed.

C L Swanson
C. L. Swanson

cc: F. M. Middleton
R. E. Crowe
Dr. W. N. Fitch
Lehn Potter
Louise Saurel
CLS:dw

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UNITED STATES GOVERNMENT

Memorandum

TO : Dr. William N. Fitch
Systems Analysis and Economics Branch

DATE: March 10, 1971

THRU : F. M. Middleton F.M.M.
Director of Research, AWTRL

FROM : Robert Smith, Chief
Treatment Optimization Research Program

SUBJECT: Cost-Effectiveness Task Force - Economics of Consolidating Sewage Treatment Plants by Means of Interceptor Sewers and Force Mains

The following material on the economics of consolidating wastewater treatment plants by means of pipelines is an expansion of the results reported to you on January 22, 1971. The objectives of this additional work were supplied in a memo from Mr. C. L. Swanson dated February 3, 1971. All of the objectives outlined in Mr. Swanson's memo have been accomplished except for a formalized way of optimizing the consolidation of three or more plants. Generalized guidelines for solving the three or more plant problem will be given here but a formalized, computer assisted, method for any number of plants will require additional work.

First, consider the two plant problem. The only question to be answered is whether to build two independent plants or one plant and a connecting pipeline. To make this decision, we need only to compute (1) the cost of building and operating two independent plants and (2) the cost of building and operating one larger plant to treat the two sources of wastewater combined plus a connecting pipeline. The second cost will depend on the pipeline length. When all costs associated with the two alternatives are known, a breakeven pipeline length can be computed which will make the cost of the two alternatives equal. If the actual distance between the plants is less than the breakeven pipe length, the more economic solution will be to build two independent plants.

The two plant problem is complicated only by the large number of variables to be considered. For example, the connecting pipeline might be a gravity sewer if the elevation of the contributor plant is sufficiently above the elevation of the receiving plant. Otherwise a force main and a pumping station will be required to connect the two point sources of wastewater. If the elevations and distance between plants are known, the average slope can be read from Figure 1.

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GRAVITY SEWERS

If the slope is adequate for a gravity sewer, the Manning formula[1] can be used to find the pipe diameter required. The diameter of gravity sewer required to transmit any average flow is shown in Figure 2. In developing the data shown in Figure 2 a roughness number of 0.013 was used as suggested by the Ten States Standards[2]. The design flow for the gravity sewer was taken as 3.5 times the average flow (at 7/10 diameter ratio) as required by the Ten States Standards. The requirement of at least 2 ft/sec velocity when the pipe is flowing full is also shown in Figure 2. Diameters above this line are prohibited to provide for a self cleaning capability. The minimum diameter of 8 inches as provided by Ten States Standards is also shown on Figure 2.

The cost associated with gravity sewers includes the amortization cost and a small maintenance cost. The cost of constructing sewers is shown in Figure 3 from various sources. The agreement is good and the relationship used is that given by Koenig[3]. This relationship is as follows in terms of December, 1970 dollars:

$$\text{Construction Cost, \$/Mile} = 1540.7(\text{ID} + 2.0436)^{1.37949} \qquad (1)$$

where, ID = inside pipe diameter, inches

The cost of maintaining the gravity sewer was taken as $40/yr/mile. Taking the rate of interest as 6% and the life of the sewer as 50 years gives the cost of transmitting wastewater by gravity sewers in terms of cents/1000 gal./mile as shown in Figure 4. Notice that these costs are given in terms of average flow rather than peak flow which was taken as 3.5 times the average flow.

FORCE MAINS

If the receiving plant is above the contributing plant, a force main and a pump station will be required. The first problem is to determine the economic diameter for the force main since a smaller diameter pipe will be less costly to construct but will have a greater frictional loss and a correspondingly higher pumping power cost. The Hazen-Williams[4] formula for frictional loss was used with a surface roughness factor of 100. Electrical power was assumed to cost one cent/Kw-Hr. The hydraulic efficiency of the pump was taken as 60% and the electrical efficiency of the driving motor was taken as 80%.

In performing the optimization to minimize the sum of the pipeline debt service plus the cost of pumping power it was assumed that the pump station would be provided with a wet well and a pump having a capacity 3.5 times the average flow into the pump station. The pump is controlled to go on and off depending on the level of water in the wet well. On the average, the pump will be operating 1/3.5 of the time. Using these assumptions the economic pipe diameter was computed using an optimization technique and the results are shown in Figure 5.

It has been shown by Koenig that the cost of constructing force mains is not significantly different from the cost of constructing gravity sewers. Equation (1) was, therefore, used to find the construction cost for force mains. Debt service was computed on a 50 yr - 6% basis.

The cost of constructing pump stations was taken from various sources and these data are shown plotted in Figure 6. The regression line marked "FWQA Peak Capacity" was provided by Mr. R. L. Michel of the Division of Facilities Construction and Operation. This relationship was used for construction cost for pump stations. The design peak flow for pump stations was taken as 3.5 times the average flow transmitted. Debt service was computed using 25 yr - 6% as a basis.

Operation and maintenance costs for pump stations were gathered from various sources and the agreement was not good. Additional data was gathered from sources in Cincinnati and Dayton, Ohio. These data agreed reasonably well with the relationship given by Southwest Research Institute under contract to OSW[5]. The SWRI relationship shown below was used in this study:

$$\text{O + M Cost, cents/1000 gal.} = 1.6103\ (\text{Peak Flow})^{-0.26257} \qquad (2)$$

where, Peak Flow = mgd

Since this relationship is in terms of the peak flow capacity, the value taken from the relationship must be multiplied by the ratio Peak Flow/Average Flow to put the cost in terms of cents/1000 gal. of average flow.

Maintenance cost for force mains was taken as $40/yr/mile.

The total cost of constructing and operating force mains can now be computed. Since the electrical power cost and pipe maintenance cost are in terms of cents/1000 gal./mile, these have been lumped with debt service for the pipeline as shown in Figure 7. The cost of pump stations in terms of cents/1000 gal. includes the debt service plus the operation and maintenance cost for the pump station. These data are also shown in Figure 7 in terms of average flow transmitted.

COST OF PLANTS

In order to compute the breakeven pipeline length, the cost of treating wastewater with various groups of processes is also needed. A study has recently been completed by Black and Veatch Consulting Engineers which gives the construction cost of all conventional processes as a function of size and provides a methodology for combining these cost estimates into a total capital cost for conventional plants made up of any set of processes. These relationships and methods have been programmed for the digital computer, and this program was used to compute the cost of activated sludge and trickling filter plants as shown in Figures 8 - 11. Two sludge disposal schemes were considered both of which used anaerobic digestion. The first scheme used sludge drying beds while the second scheme used vacuum filtration and multiple hearth incineration. A complete list of the processes used is shown on Figures 8 - 11.

The complete plant costs shown in Figures 8 - 11 have been compared to the most recent construction cost data from Mr. R. L. Michel of the Division of Facilities Construction and Operation. Mr. Michel's data agrees very well for activated sludge plants greater than about 4 mgd. Below 4 mgd the Black and Veatch data is greater. For example, Michel would estimate the cost of a one mgd plant as $590,000 as compared to about $850,000 for Black and Veatch. The latest estimates for operation and maintenance from Mr. Michel agree with Black and Veatch in the larger sizes, above about 15 mgd. The difference becomes progressively larger as the plant size decreases. For example, at one mgd Michel estimates about 8.6 cents/1000 gallons for O + M as compared to about 18.5 cents/1000 gallons from Black and Veatch. This is due primarily to the fact that Black and Veatch has based their estimate for manpower on what they believe is required for good operation while Michel's data reflect the manpower actually being expended for operation and maintenance in federally funded plants.

A recent study completed by Mr. Michel has shown that out of 391 plants surveyed only 8.9% used vacuum filters for dewatering. Out of 700 plants surveyed for ultimate disposal methods only 2.4% used incineration. Based on this information the sludge drying bed method of disposal is more representative of present practice.

Cost of raw sewage pumping at the plant is shown in Figure 16.

Total cost and amortization cost for groups of advanced processes are shown in Figures 12 - 15. The alum addition cost is based on a dose of 144 mg/l of alum plus additional sludge handling facilities (anaerobic digesters and sludge drying beds) to handle the additional sludge production. Recent studies have shown that with alum addition the amount of sludge produced in an activated sludge plant is increased by about 25%.

Lime clarification cost is based on data shown in "Cost and Performance for Tertiary Wastewater Treating Processes" TWRC-9. In this report it is shown that recovery of the lime sludge by recalcination will probably not be economic in sizes less than 10 mgd. A two-stage lime clarification system is assumed.

The cost of multi-media filtration and granular carbon adsorption was also taken from Report No. TWRC-9. All costs are adjusted to December, 1970 and debt service is computed assuming 25 yr plant life and 6% interest.

EFFECT OF EXISTING FACILITIES

The breakeven pipeline length is also controlled by the relationship between existing facilities and the required facilities. For example, the following three cases will be considered:

Case I: Neither community has an existing sewage treatment Plant.

Case II: One community, A, owns and operates an activated sludge plant with sufficient excess capacity to serve the second community, B, which has a need for treatment but does not own a plant.

Case III: One community, A, owns and operates an activated sludge plant with no excess capacity. Community B has no plant but community A offers to accept the wastewater of community B if additional capacity is provided at the plant of community A.

Other cases might occur but these can be handled along the lines shown below.

HAND CALCULATION FOR BREAKEVEN PIPELINE LENGTH

As mentioned previously, to calculate the breakeven pipeline length for consolidation of two plants, it is necessary to set the cost of owning and operating two independently operated plants equal to the cost of owning and operating a combined plant plus a connecting pipeline. This is shown algebraically in Appendix I.

Equations (2) and (3) of Appendix I show how to compute breakeven pipeline length from the cost of all facilities. The cost of contributor, receiving, and combined plants are shown in equations 4 - 12 for the three cases described on page 5.

For Case I the equations are self explanatory. For Case II it is assumed that the amortization cost for the over-sized receiving plant will be the same whether or not consolidation is implemented. In Case III it is assumed that if consolidation is implemented, it will be necessary to build facilities for treatment of the flow from the contributor community on the site of the receiving plant. In Case III the operation and maintenace cost is computed at the size of the combined plant.

In general, Case II is the most favorable condition for consolidation and thus yields the longest breakeven pipeline length. The next most favorable case is Case I which yields, in general, the intermediate pipeline length. Case III is the least attractive for consolidation and, in general, yields the shortest breakeven pipeline length.

Hand calculation forms have been prepared as Sheets 1, 2, and 3. For a single case it is not necessary to fill all of the spaces in the three sheets, however, it is a relatively easy chore to fill out the three sheets and to calculate the breakeven pipeline length. Sheet 1 lists all of the total treatment costs associated with the three plants. Sheet 2 lists all of the debt service or amortization costs for the three plants. On Sheet 3 the cost of the pipeline is combined with the cost of plants to arrive at the breakeven pipeline length.

Three representative hand calculations have been worked out to illustrate the procedure. Notice that in Cases I and III raw sewage pumping at the receiving plant will be required only for the flow from the receiving community and not for the additional flow from the contributing community. In Case II it is assumed that the raw sewage pumping station has been sized to handle the sum of the contributor and receiving plant. The combined flow, Q_t, is always equal to the sum of the contributor, Q_c, plus the receiving plant flow, Q_r.

Notice that the costs given in Figures 8 - 11 are adjusted to January, 1970 and must be multiplied by a factor of about 1.07 before use in Sheets 1 and 2. All other costs to be used in the hand calculation have been adjusted to December, 1970.

The computation of breakeven pipeline length shown on Sheet 3 involves the subtraction of two large numbers which maximizes the error associated with the breakeven pipeline length. The cost estimates are themselves subject to error and the breakeven pipeline length should, therefore, be taken as a general guide and not as an absolute criterion for consolidation. The error to be expected in computing the breakeven length is probably about ± 30 - 50%.

The slope for gravity sewers is understood to be downhill from contributor to receiver and uphill from contributor to receiver for force mains.

COMPUTER PROGRAM OUTPUT

A computer program has been written to perform the computations shown in the hand calculation sheets and some sample output from this program are shown in Figures 17 - 28. The following combinations of input to the program have been computed and are available at Robert A. Taft Water Research Laboratory in Cincinnati.

TREATMENT TRAINS

1. Activated Sludge, S.B.
2. Activated Sludge, S.B., Alum Addition
3. Activated Sludge, S.B., Lime Clarification
4. Activated Sludge, S.B., Lime Clarification, Filtration
5. Activated Sludge, S.B., Lime Clarification, Filtration, Carbon Adsorption
6. Trickling Filter, S.B.
7. Trickling Filter, S.B., Lime Clarification
8. Trickling Filter, S.B., Lime Clarification, Filtration
9. Trickling Filter, S.B., Lime Clarification, Filtration, Carbon Adsorption

Computations for each of these nine treatment trains have been made using both gravity sewers and force mains. Two slopes, 0.001 and 0.005, are used for gravity sewers and two slopes, 0.00 and 0.005 are used for force mains. Each of these thirty-six combinations have been run for all three cases giving a total of 108 cases. In addition to this, when advanced treatment is considered, the possibility exists that the receiver plant will not require advanced treatment while the contributor plant will require advanced treatment. Since advanced treatment is considered in only seven of the above treatment trains, this will add another 84 cases using the same slope for gravity sewers and force mains. A total of 192 cases are, therefore, available. The term economic pipe length used on the computer printouts means breakeven pipe length.

SUMMARY OF COMPUTED RESULTS

Looking over the 192 pages of computed results we can make some generalized conclusions. First consider Case I where the slope of both gravity sewers and force mains is set at 0.005 ft/ft and all plants have similar treatment. As the size of the contributor plant is increased, that is, as the eye moves down the page of computations, the breakeven pipeline length (economic pipe length, miles) decreases sharply for force mains but changes less for gravity sewers.

For example, when the treatment train consists of only raw sewage pumps and activated sludge plant, the breakeven force main length is about 13 miles for 1 mgd and decreases as the size of the contributor increases. The length also increases as the size of the receiving plant increases. For example, the length is zero for contributors greater than 60 mgd. For a 20 mgd contributor the breakeven length (BEL) varies between 2 miles and 0.17 miles. For the same case gravity sewers have a BEL of 15-20 miles for all sizes of contributor and receiver.

All alum addition has little effect on the BEL because the total cost, ¢/Kgal, is relatively independent of plant size.

Adding lime clarification increases the maximum BEL for force mains to about 20 miles for 1 mgd combined with 40-100 mgd combination. All BEL's are positive, the least being 3 miles for combining two 100 mgd plants. The BEL for gravity sewers is about 20 - 25 miles for all combinations.

Adding filtration to the lime clarification further increases the BEL. For force mains the range is 25 - 5 miles. For gravity sewers the range is 20 - 30 miles with minimum effect of the size of plant.

Adding carbon adsorption to the tertiary treatment train increases the BEL to 40 - 10 miles depending on the plant size for force mains. For gravity sewers the BEL is in the range 35 - 50 with minimum effect of plant size.

Substituting trickling filter plants for activated sludge plants tends to reduce the BEL but not to a very great extent. For example, for trickling filters and raw sewage pumps the maximum BEL is about 11 miles instead of 13 miles. All contributors less than 20 mgd are zero with the 100 - 20 mgd combination yielding a BEL of 0.75 miles. Notice that the breakeven distance would have been negative according to our computing relationship but this is set equal to zero in the program.

The average BEL for the whole tertiary treatment train with trickling filters averages about 35 - 40 miles for gravity sewers and the length is relatively independent of plant size.

Now, for Case II and again using the slope of 0.005 for both force mains and sewers we note that the BEL is increased. For activated sludge and raw sewage pumps the range for force mains is from about 15 miles to a minimum of 5 miles at the 100 - 100 mgd combination while BEL for gravity sewers ranges between 20 - 30 miles. Using the complete tertiary treatment train the BEL's range from 40 to 30 miles. For gravity sewers the average BEL is about 55 miles.

For Case III the BEL's are less than Case I. Using activated sludge and raw sewage pumps the BEL for 1 mgd is about 6 miles. All cases where the contributor is greater than 10 mgd are zero. The BEL for 10 mgd and 100 mgd is 0.3 miles. For gravity sewers the range is 8 - 12 miles.

Using the whole tertiary train with Case III and force mains give BEL's ranging between 20 miles and 6 miles. For gravity sewers the range is 25 - 35 miles.

Now if we change the slope of the force mains to zero slope and the slope of gravity sewers to 0.001, the BEL's will be increased for the force mains and decreased for the gravity sewers. For example, with activated sludge, raw sewage pumps, and Case I, the BEL averages about 10 miles for gravity sewers. For force mains the maximum for 1 mgd averages about 15 miles. All contributors greater than 40 mgd are zero. The 20 - 100 mgd combination has a BEL of 2.7 miles.

Using the complete tertiary treatment train gives an average length of gravity sewer of about 27 miles. The force main BEL's vary from 40 - 15 miles.

Finally, we can consider Case I where the contributor plant requires advanced treatment while the receiver plant needs only have conventional secondary treatment. When activated sludge and lime treatment is used in the contributor and activated sludge in the receiver, the BEL for force mains is more independent of the contributor plant and averages about 20 - 25 miles for zero slope and 12 - 22 miles of .005 slope. For gravity sewers the BEL's are in the range 20 - 30 miles for .001 slope and 30 - 45 miles for .005 slope.

For complete tertiary treatment including lime clarification, filtration, and carbon adsorption, Case I, the BEL for force mains averages about fifty miles for zero slope and 40 miles for .005 slope. For gravity sewers the range of BEL is 40 - 65 miles.

For Case II, contributor with lime clarification, the BEL for force mains is 25 - 30 miles with zero slope and 20 - 25 miles with .005 slope. For gravity sewers the BEL is 25 - 40 miles with .001 slope and 35 - 60 miles with .005 slope.

For Case III, contributor with lime treatment, the BEL for force mains was 10 - 15 miles with zero slope and 7 - 12 miles with .005 slope. The corresponding BEL for gravity sewers was 12 - 22 miles with .001 slope and 20 - 35 miles with .005 slope. For complete tertiary treatment at the contributor plant the BEL for force mains averaged about 32 miles with zero slope and 25 miles with .005 slope. The corresponding length for gravity sewers was 25 - 50 miles with .001 slope and 40 - 70 miles with .005 slope.

The difficulty in summarizing this large amount of computed results is obvious from the above paragraphs. If specific individual cases are needed, they can be computed using the digital program in Cincinnati. For assistance call Mr. R. G. Eilers at AC 513/871-1820, ext. 288.

THREE OR MORE PLANTS

When three or more plants must be considered for consolidation, three questions may have to be answered instead of one. These questions are listed below.

1. Identify the communities to be assigned the role of receiver.
2. Of the non-receiving communities identify the group to be consolidated with each receiving community.
3. Find the most economic pipe network to deliver the wastewater from contributing communities to each receiver plant.

In general, the larger plants will be assigned the role of receiver. However, topography, existing structures and equipment, or political considerations might cause smaller plants to be assigned the receiver role. If we assume that the receivers can be identified, the next step is to identify the group of contributors to be associated with each receiver. The breakeven distances for each contributor associated with each receiver can be calculated. The decision to consolidate should then be made for each plant based on the difference between actual and breakeven distances. If some plants are marked for independent operation, this decision should be reconsidered using the size of the consolidated receiver instead of the size of the independent receiver. If the decision is for independent operation after this reconsideration, the decision should stand.

When the group of contributors associated with each receiver have been determined, transhipment must be considered. By transhipment we mean piping the water to the receiver by way of other contributing pumping stations. In this way the economy of scale for pieplines can be used to reduce the collection cost. Consideration of transhipment might also qualify some plants for consolidation which had previously been marked for independent operation.

This procedure sounds involved and it is involved if a formalized solution is required. As a matter of fact, common sense will probably suffice to arrive at the economic solution in most cases.

R Smith
Robert Smith

Attachments

REFERENCES

1. "Clay Pipe Engineering Manual", Clay Sewer Pipe Association Inc., Columbus 15, Ohio, 1950.
2. "Recommended Standards for Sewage Works", Great Lakes - Upper Mississippi River Board of State Sanitary Engineers, 1968 Edition.
3. Louis Koenig, "The Cost of Pipelines in the United States", Louis Koenig-Research, San Antonio, Texas, June, 1970.
4. "Cameron Hydraulic Data", Ingersoll-Rand Co., New York, N.Y., 1962.
5. "Desalting Cost Calculating Procedures", Office of Saline Water Report No. 555.

DEFINITIONS

Q_c = volume flow from contributing community, mgd

Q_r = volume flow from receiving community, mgd

Q_t = volume flow from both communities, $Q_c + Q_r$, mgd

C_{rsp} = total cost of raw sewage pumping at the plant, cents/Kgal

C_s = total cost of gravity sewers, cents/Kgal/mile

C_{fm} = total cost of force mains, cents/Kgal/mile

C_{ps} = total cost of pump stations for force mains, cents/Kgal

T_c = total cost of treatment at contributor community, (cents/Kgal) x mgd

T_r = total cost of treatment at receiving community, (cents/Kgal) x mgd

T_{cr} = total cost of treatment in combined plant, (cents/Kgal) x mgd

L = breakeven pipeline length, miles

C_1 = total cost of activated sludge plants in drying beds, cents/Kgal

C_2 = total cost of activated sludge plants with vacuum filtration and incineration, cents/Kgal

C_3 = total cost of trickling filter plants with sludge drying beds, cents/Kgal

C_4 = total cost of trickling filter plants with vacuum filtration and incineration, cents/Kgal

C_5 = total cost of alum addition, cents/Kgal

C_6 = total cost of lime clarification, cents/Kgal

C_7 = total cost of multi-media filtration, cents/Kgal

C_8 = total cost of granular carbon adsorption, cents/Kgal

A_i = debt service or amortization cost on i'th process, ¢/Kgal

APPENDIX I

The first step in finding the breakeven pipeline length is to set the cost of constructing and operating the two plants independently equal to the cost of building and operating the combined plant plus the pipeline. For a gravity sewer this is shown by the following equation. See page 13 for definitions.

$$T_c + T_r = T_{cr} + L\ Q_c C_s(Q_c) \tag{1}$$

solving this equation for L

$$L = \frac{T_c + T_r - T_{cr}}{Q_c\ C_s(Q_c)} \tag{2}$$

By $C_5(Q_c)$ we mean the cost of the gravity sewer in cents/Kgal/mile at the average flow Q_c. The corresponding equation for force mains is written as follows:

$$L = \frac{T_c + T_r - T_{cr} - Q_c\ C_{ps}(Q_c)}{Q_c C_{fm}(Q_c)} \tag{3}$$

The form taken by T_c, T_r, and T_{cr} will depend on the case being considered. For example for Case I we have the following expressions:

$$T_c = Q_c\ C_{rsp}(Q_c) + Q_c \sum C_i(Q_c) \tag{4}$$

$$T_r = Q_r\ C_{rsp}(Q_r) + Q_r \sum C_i(Q_r) \tag{5}$$

$$T_{cr} = Q_r\ C_{rsp}(Q_r) + Q_t \sum C_i(Q_t) \tag{6}$$

The C_i's appearing in the summation will correspond to the group of treatment processes included at the contributor, receiving, and combined plants.

For Cases II and III we must consider the debt service as well as the total treatment cost. $A_i(Q_c)$ will mean the debt service on the i'th process at the size of the contributor plant in cents/Kgal. T_c, T_r and T_{cr} for Cases II and III are shown below.

Case II

$$T_c = Q_c C_{rsp}(Q_c) + Q_c \sum C_i(Q_c) \qquad (7)$$

$$T_r = Q_t A_{rsp}(Q_t) + Q_t \sum A_i(Q_t) + Q_r(C_{rsp}(Q_r) - A_{rsp}(Q_r)) + Q_r \sum [C_i(Q_r) - A_i(Q_r)] \qquad (8)$$

$$T_{cr} = Q_t C_{rsp}(Q_t) + Q_t \sum C_i(Q_t) \qquad (9)$$

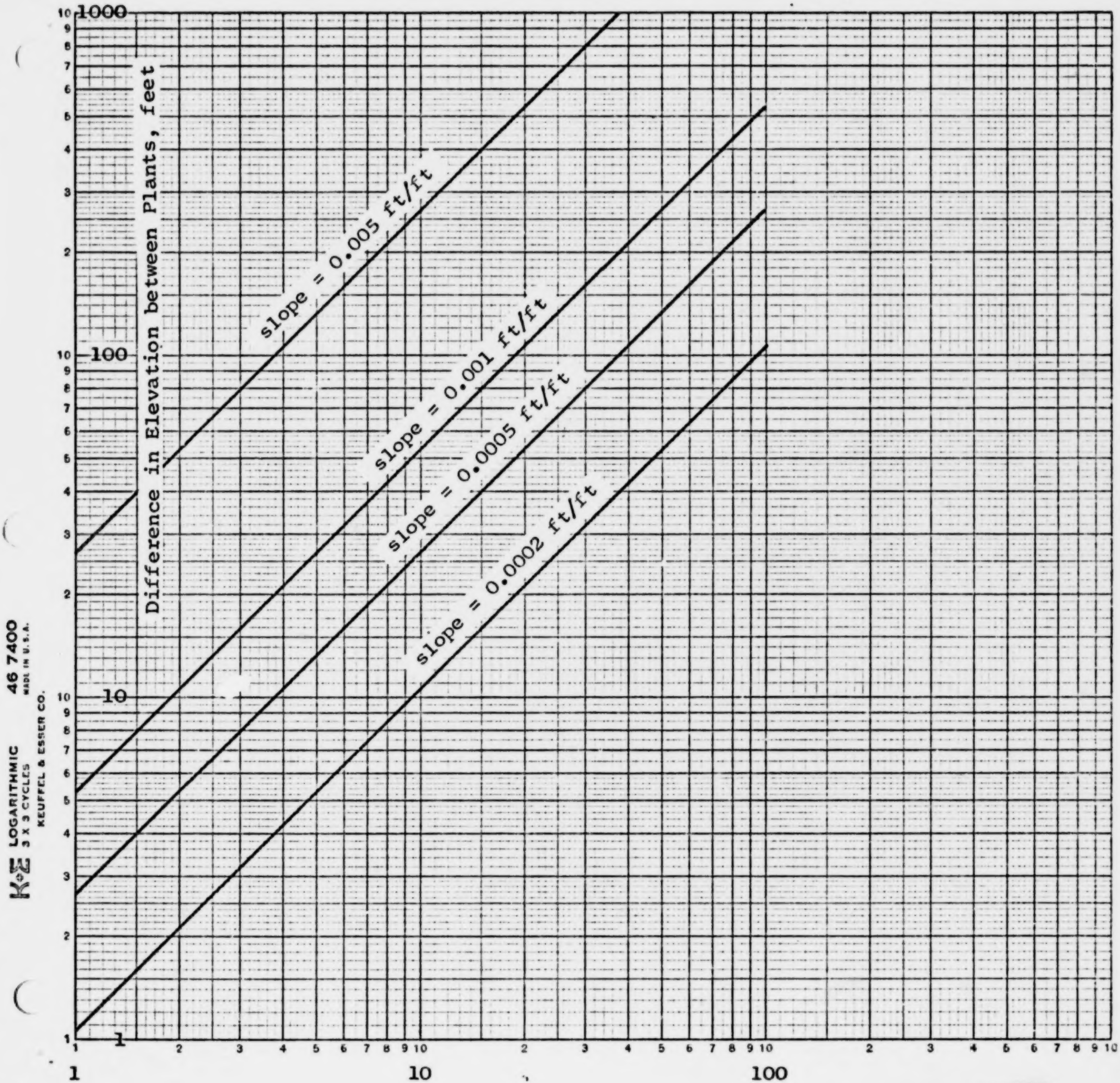
Case III

$$T_c = Q_c C_{rsp}(Q_c) + Q_c \sum C_i(Q_c) \qquad (10)$$

$$T_r = Q_r C_{rsp}(Q_r) + Q_r \sum C_i(Q_r) \qquad (11)$$

$$T_{cr} = Q_r C_{rsp}(Q_r) + Q_r \sum A_i(Q_r) + Q_c \sum A_i(Q_c) + Q_t \sum [C_i(Q_t) - A_i(Q_t)] \qquad (12)$$

AVERAGE SLOPE BASED ON DISTANCE AND ELEVATION
DIFFERENCE BETWEEN PLANTS



Distance between Plants, miles

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FIGURE 1

GRAVITY SEWERS

INSIDE PIPE DIAMETER NEEDED TO TRANSMIT ANY AVERAGE VOLUME FLOW

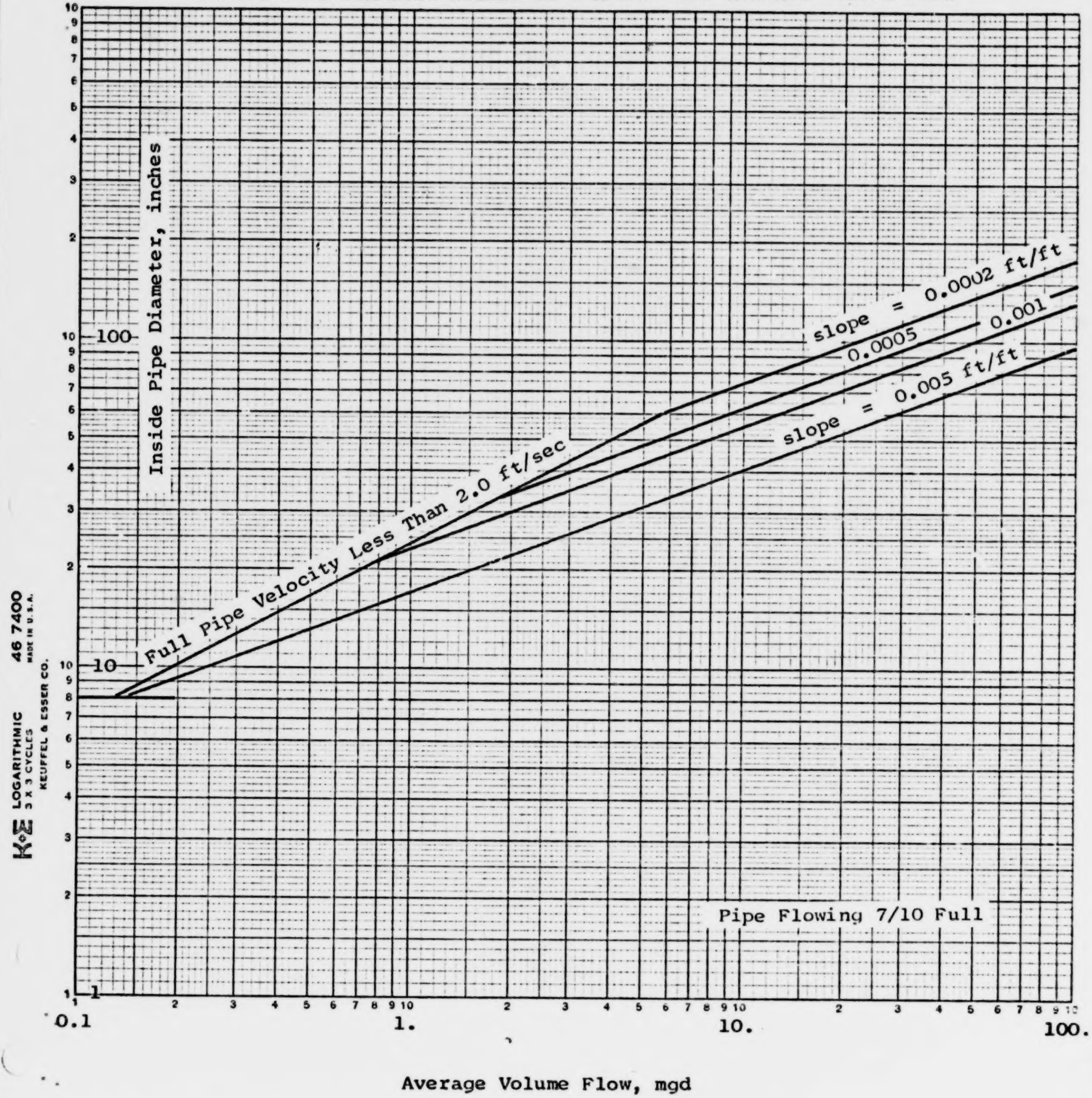


FIGURE 2

CONSTRUCTION COST FOR PIPELINES
April, 1970

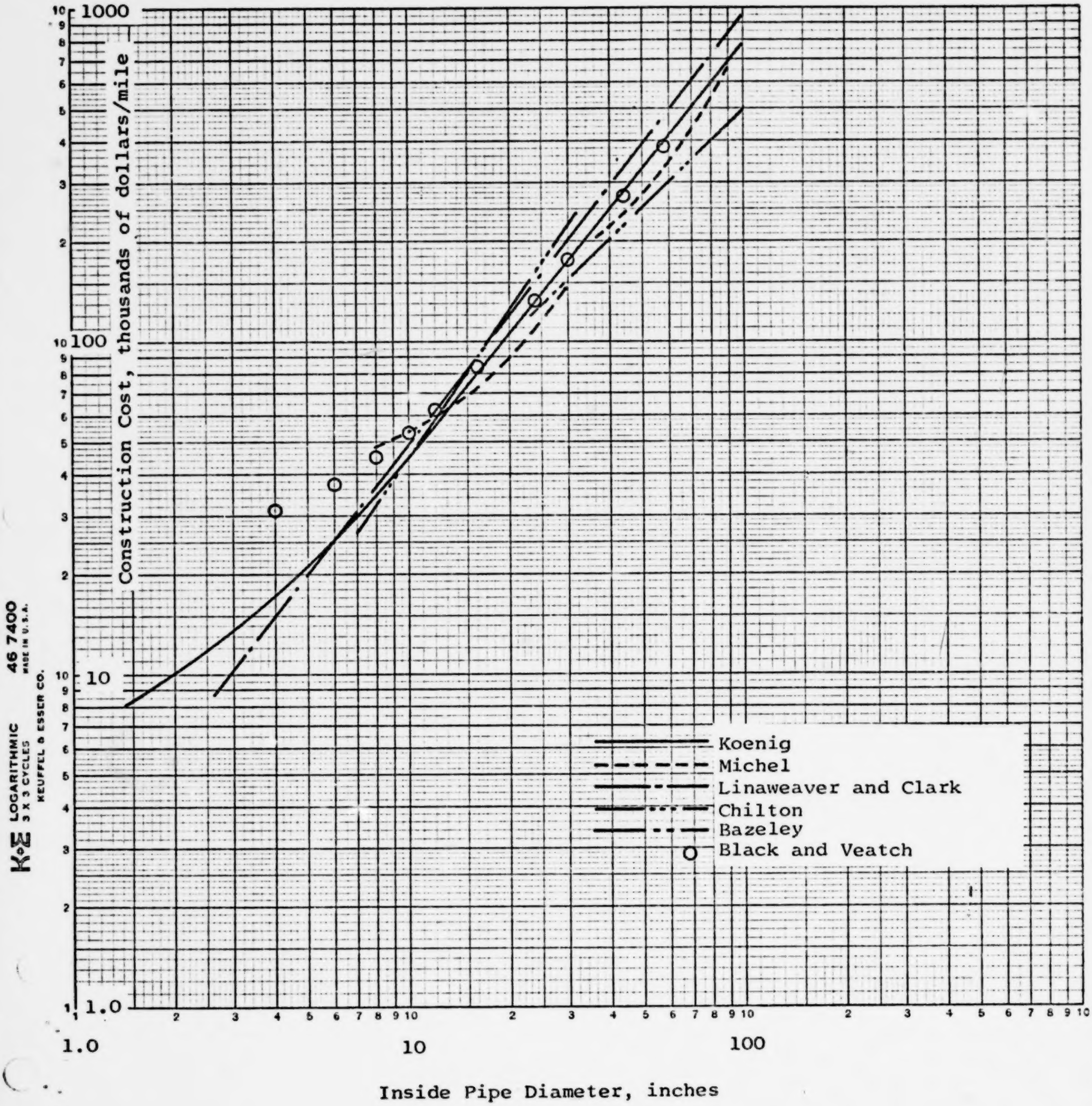
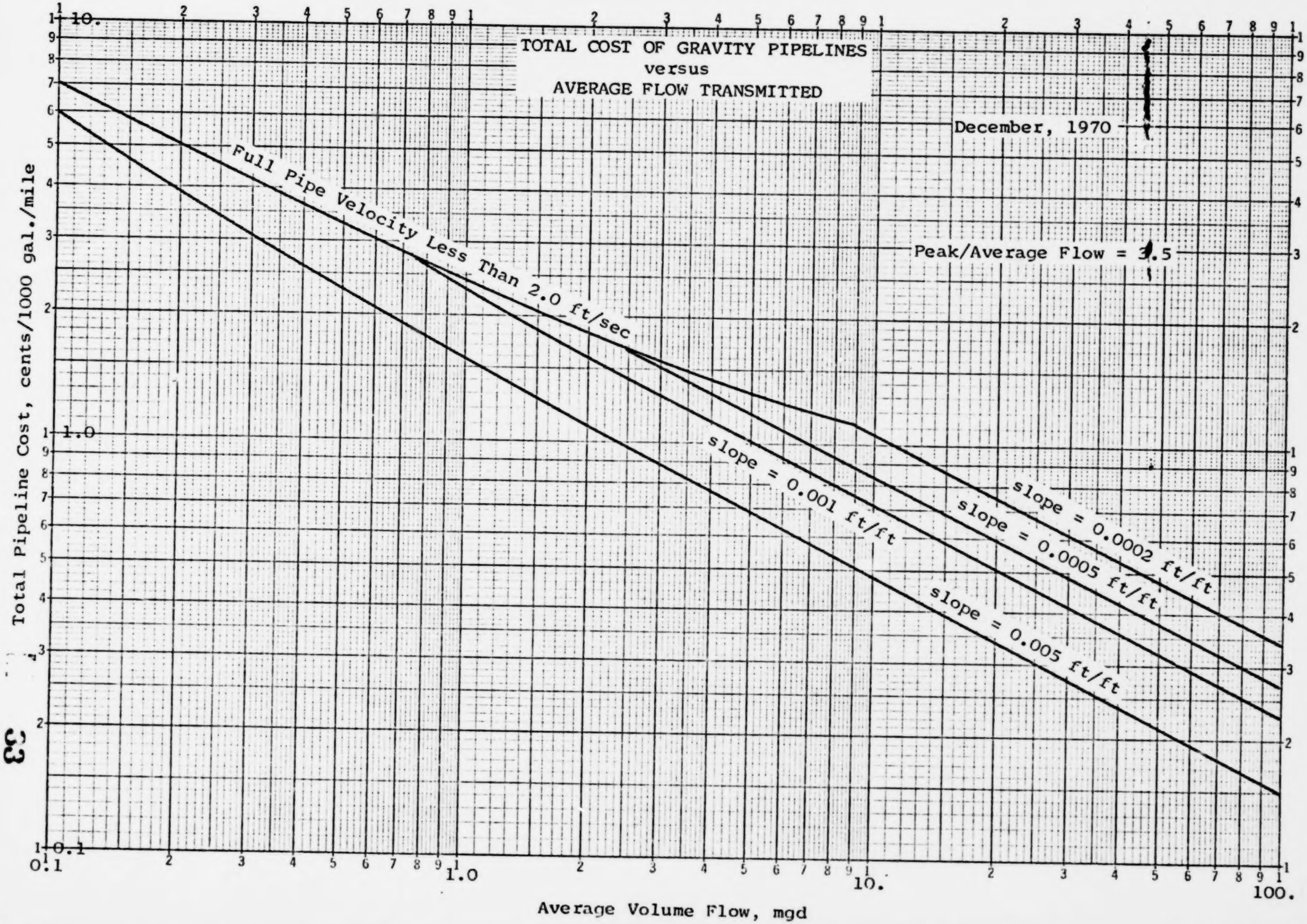


FIGURE 3

K+E LOGARITHMIC 2 X 3 CYCLES 46 7320 MADE IN U.S.A.
KEUFFEL & ESSER CO.



TOTAL COST OF GRAVITY PIPELINES
versus
AVERAGE FLOW TRANSMITTED

December, 1970

Peak/Average Flow = 3.5

FIGURE 4

ECONOMIC PIPE DIAMETER
versus
AVERAGE FLOW TRANSMITTED

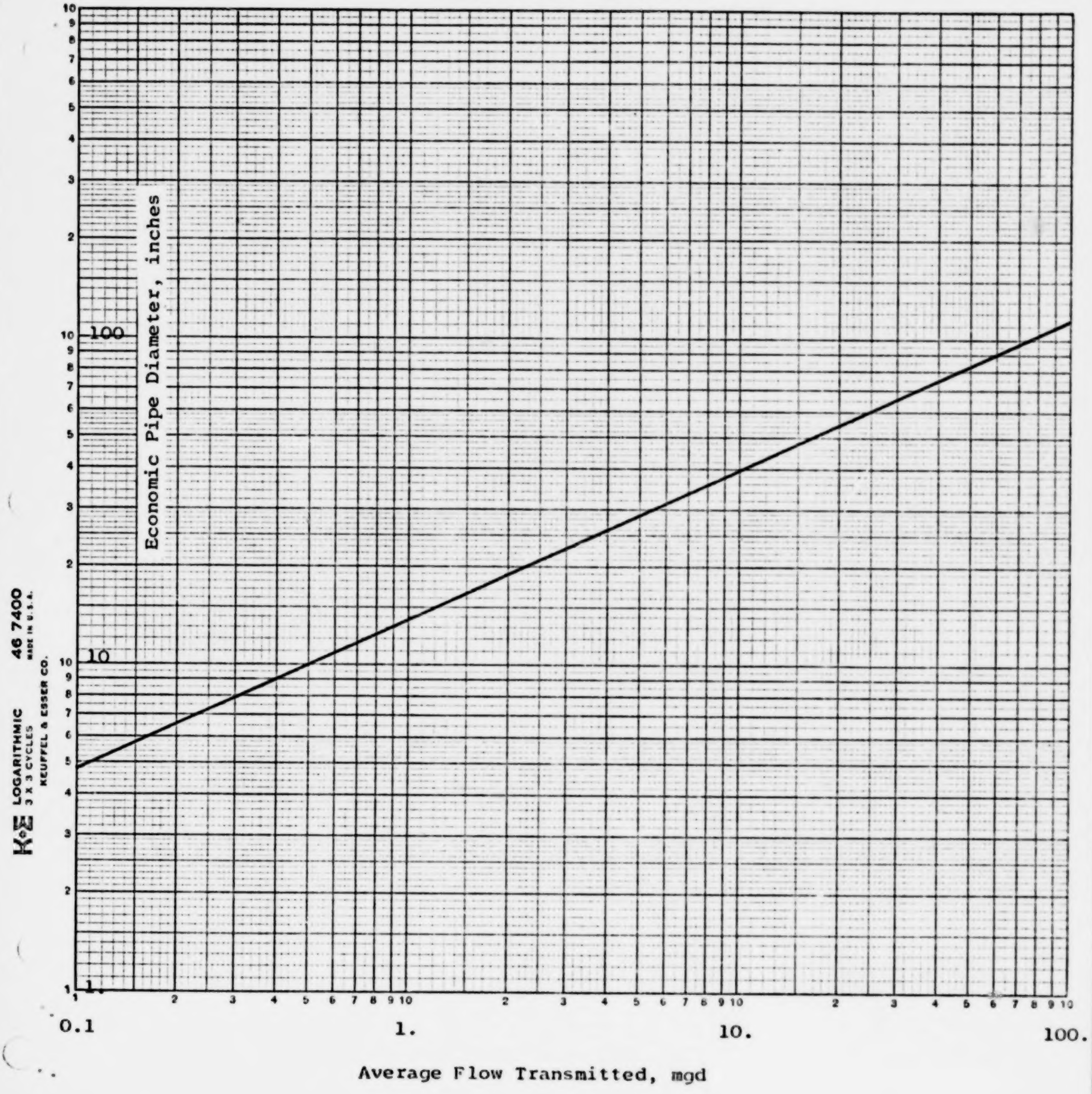


FIGURE 5

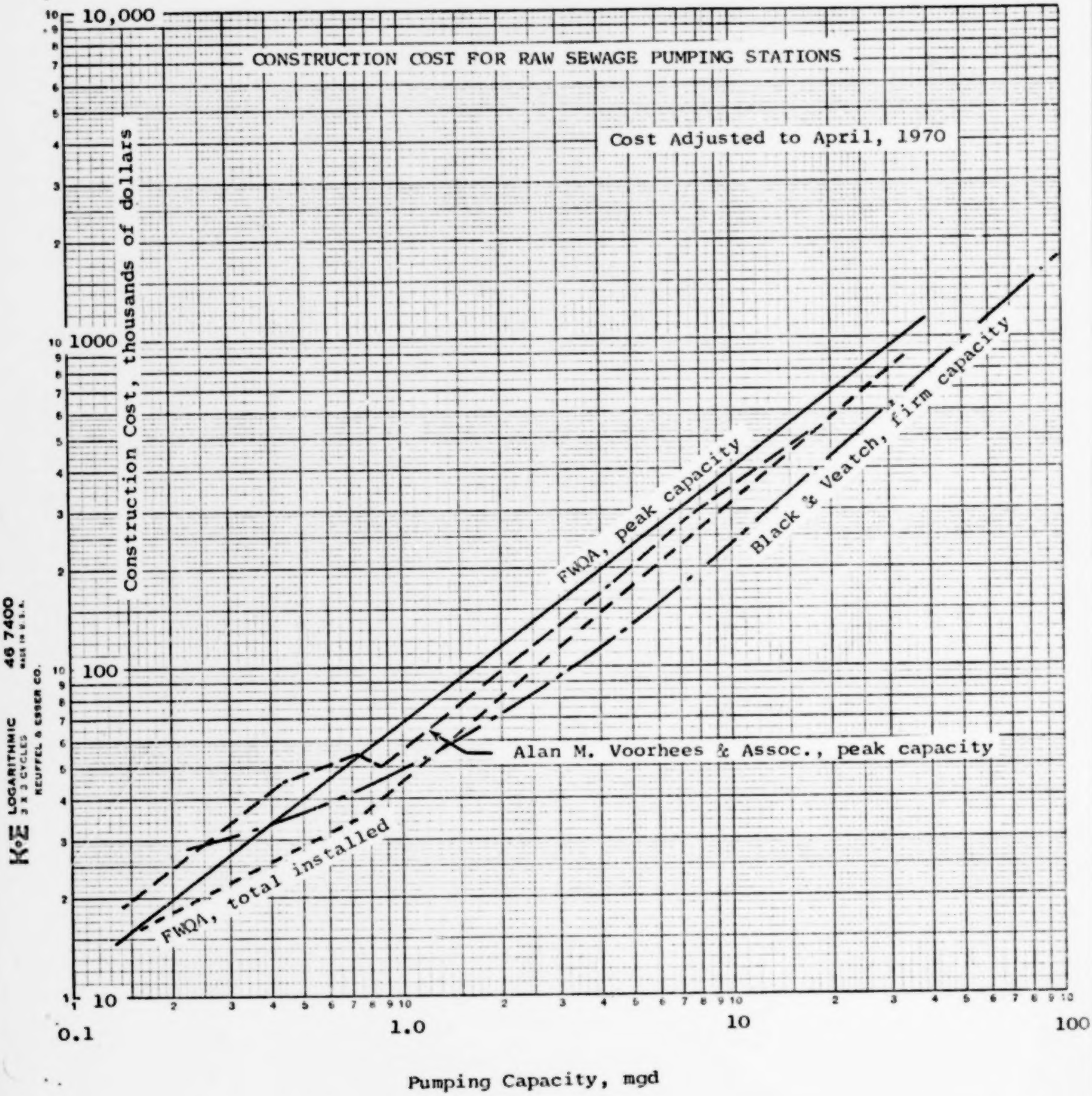

CONSTRUCTION COST FOR RAW SEWAGE PUMPING STATIONS
Cost Adjusted to April, 1970
Construction Cost, thousands of dollars
10,000
1000
100
10
0.1
1.0
10
100
Pumping Capacity, mgd
FWQA, peak capacity
Black & Veatch, firm capacity
Alan M. Voorhees & Assoc., peak capacity
FWQA, total installed
K&E LOGARITHMIC 3 X 3 CYCLES KEUFFEL & ESSER CO.
46 7400 MADE IN U.S.A.

FIGURE 6

TOTAL COST OF PUMP STATIONS AND FORCE MAINS
versus
AVERAGE FLOW TRANSMITTED

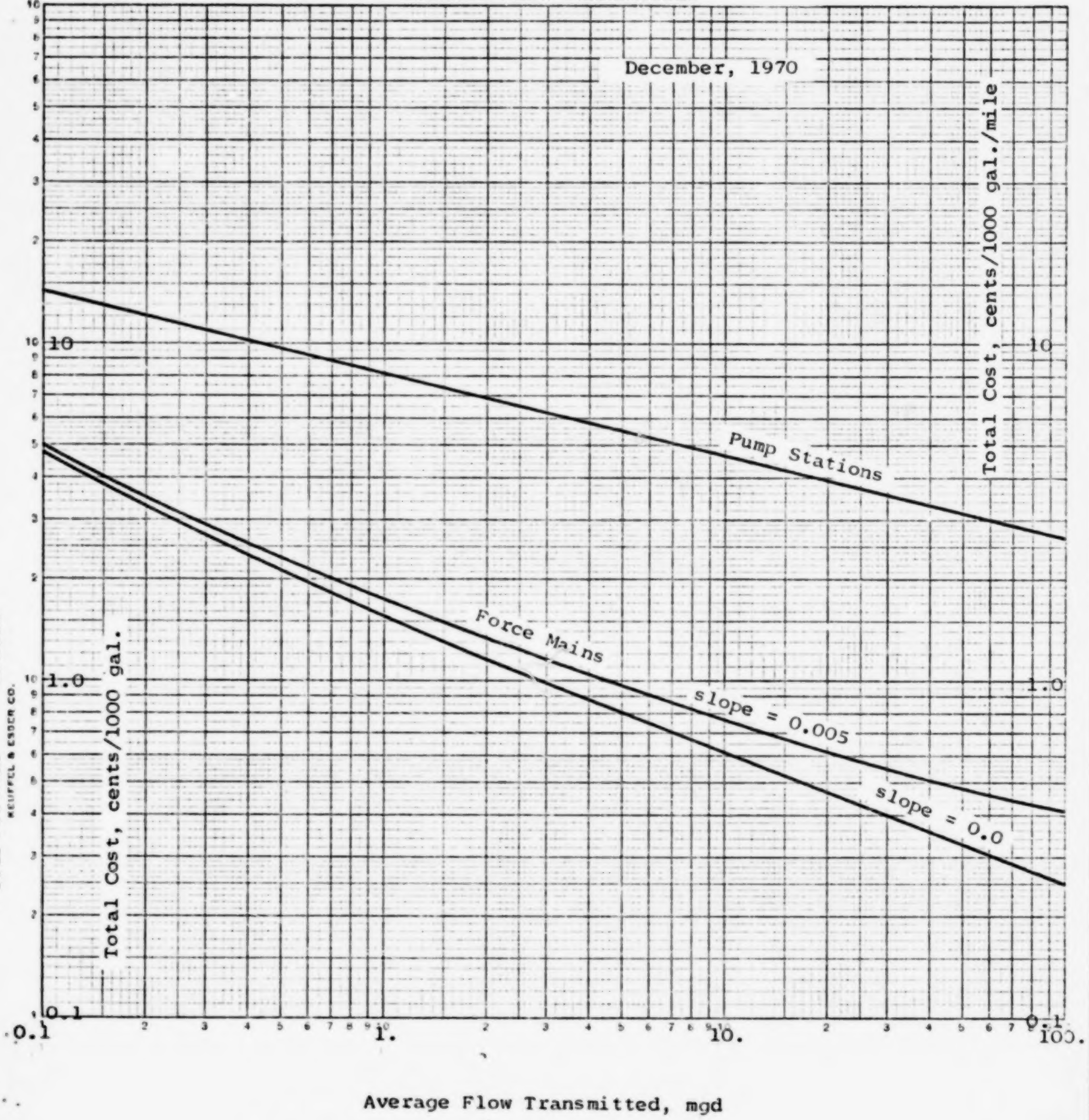
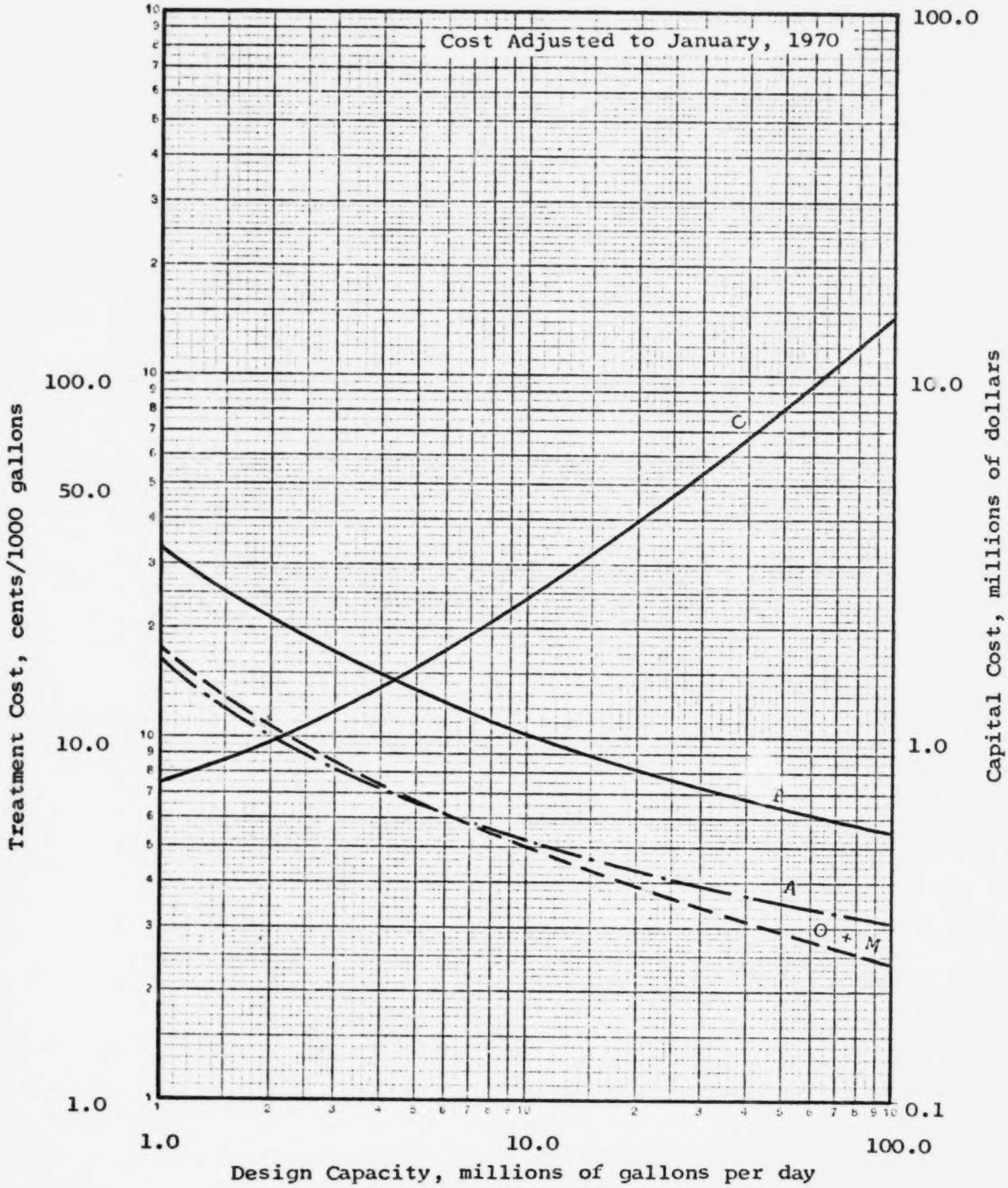


FIGURE 7

ACTIVATED SLUDGE PLANTS

Including: Preliminary Treatment-G+F+S, Primary Sedimentation, Primary Sludge Pumps, Aerators, Diffused Air System, Final Settlers-Multiple, Recirculation Pumps, Sludge Thickener, Anaerobic Digesters, Sludge Drying Beds, Chlorination, Laboratory

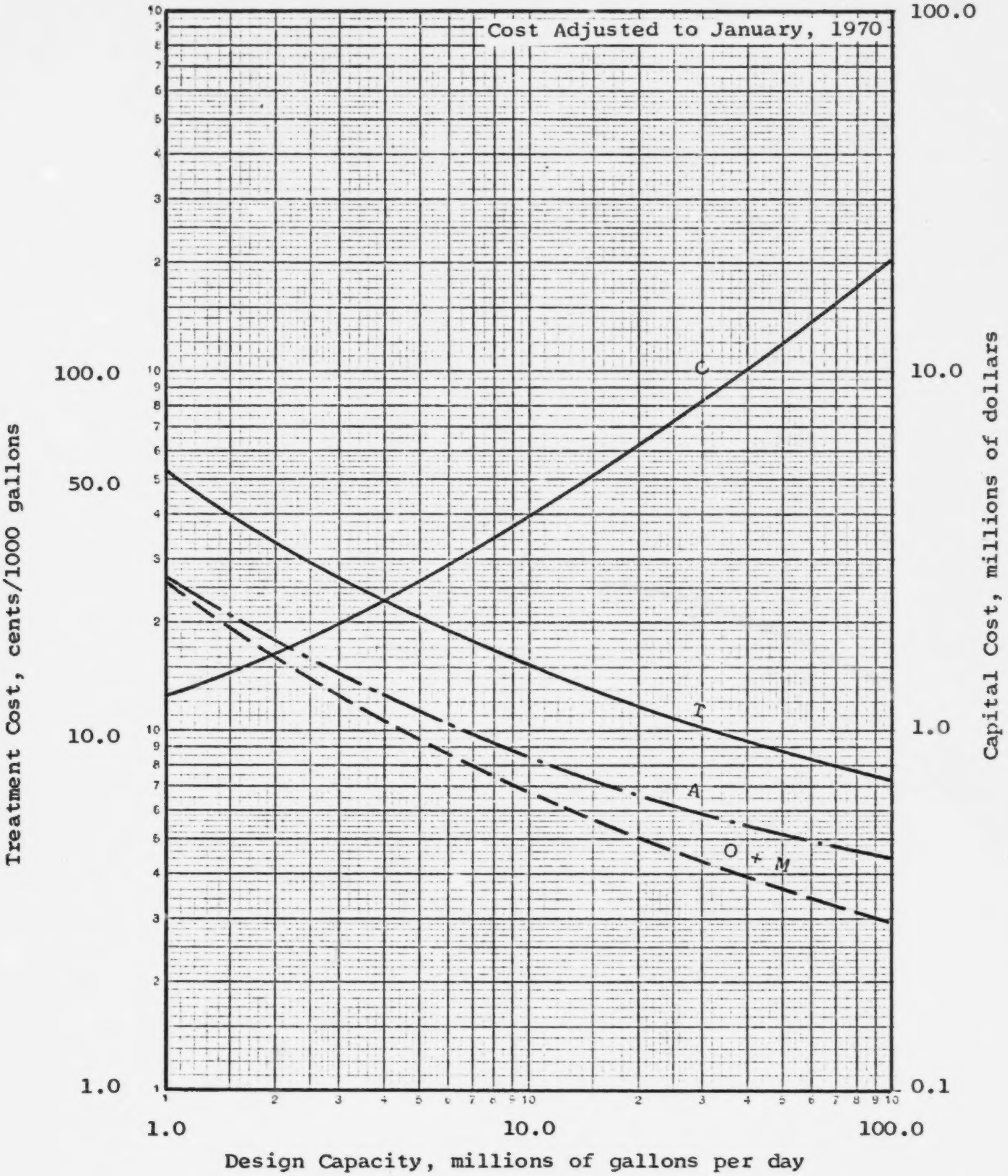


C = Capital Cost, millions of dollars
A = Debt Service, cents per 1000 gallons (6% - 25 yr.)
O + M = Operating and Maintenance Cost, cents per 1000 gallons
T = Total Treatment Cost, cents per 1000 gallons

FIGURE 8

ACTIVATED SLUDGE PLANTS

Including: Preliminary Treatment-G+F+S, Primary Sedimentation, Primary Sludge Pumps, Aerators, Diffused Air System, Final Settlers-Multiple, Recirculation Pumps, Sludge Thickener, Anaerobic Digesters, Sludge Holding Tanks, Vacuum Filtration, Multiple Hearth Incineration, Chlorination, Laboratory

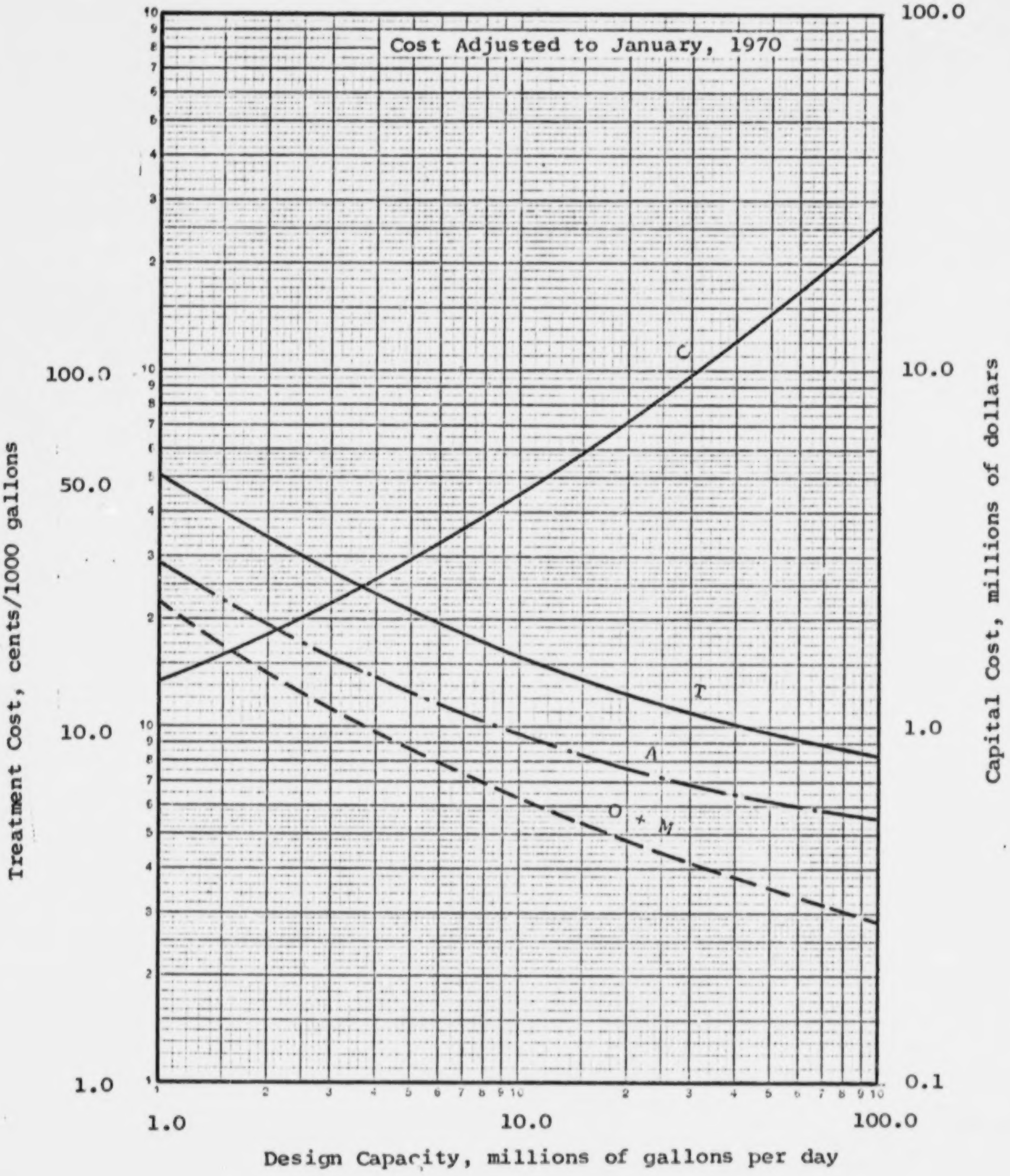


C = Capital Cost, millions of dollars
A = Debt Service, cents per 1000 gallons (6% - 25 yr.)
O + M = Operating and Maintenance Cost, cents per 1000 gallons
T = Total Treatment Cost, cents per 1000 gallons

FIGURE 9

TRICKLING FILTER PLANTS

Including: Preliminary Treatment-G+F+S, Primary Sedimentation-Multiple, Primary Sludge Pumps, Trickling Filters, Final Sedimentation-Multiple, Recirculation Pumps, Sludge Thickener, Anaerobic Digestion, Sludge Holding Tanks, Vacuum Filtration, Multiple Hearth Incineration, Chlorination, Laboratory

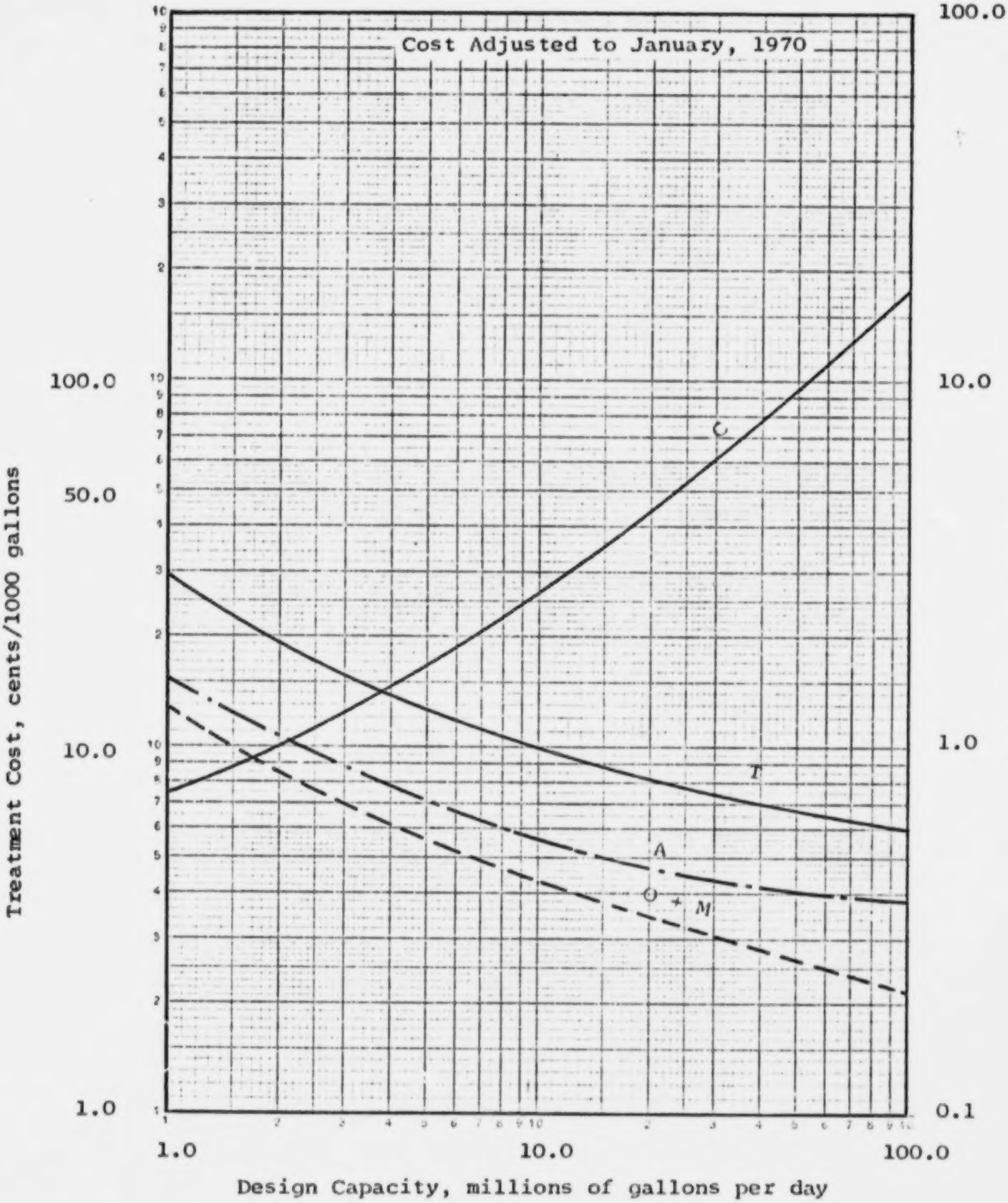


C = Capital Cost, millions of dollars
A = Debt Service, cents per 1000 gallons (6% - 25 yr.)
O + M = Operating and Maintenance Cost, cents per 1000 gallons
T = Total Treatment Cost, cents per 1000 gallons

FIGURE 10

TRICKLING FILTER PLANTS

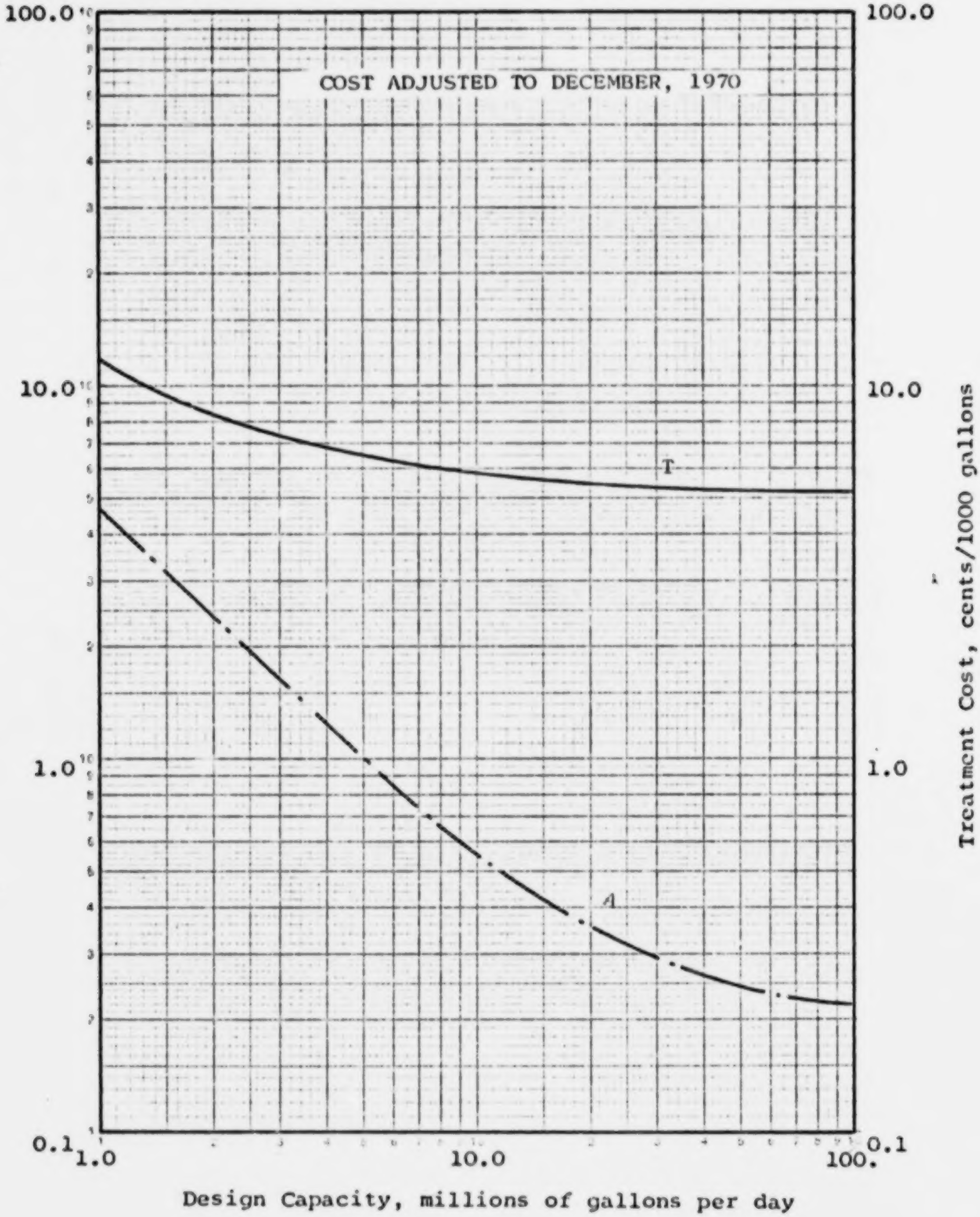
Including: Preliminary Treatment-G+F+S, Primary Sedimentation-Multiple, Primary Sludge Pumps, Trickling Filters, Final Sedimentation-Multiple, Recirculation Pumps, Sludge Thickener, Anaerobic Digestion, Sludge Drying Beds, Chlorination, Laboratory



C = Capital Cost, millions of dollars
A = Debt Service, cents per 1000 gallons (6% - 25 yr.)
O + M = Operating and Maintenance Cost, cents per 1000 gallons
T = Total Treatment Cost, cents per 1000 gallons

FIGURE 11

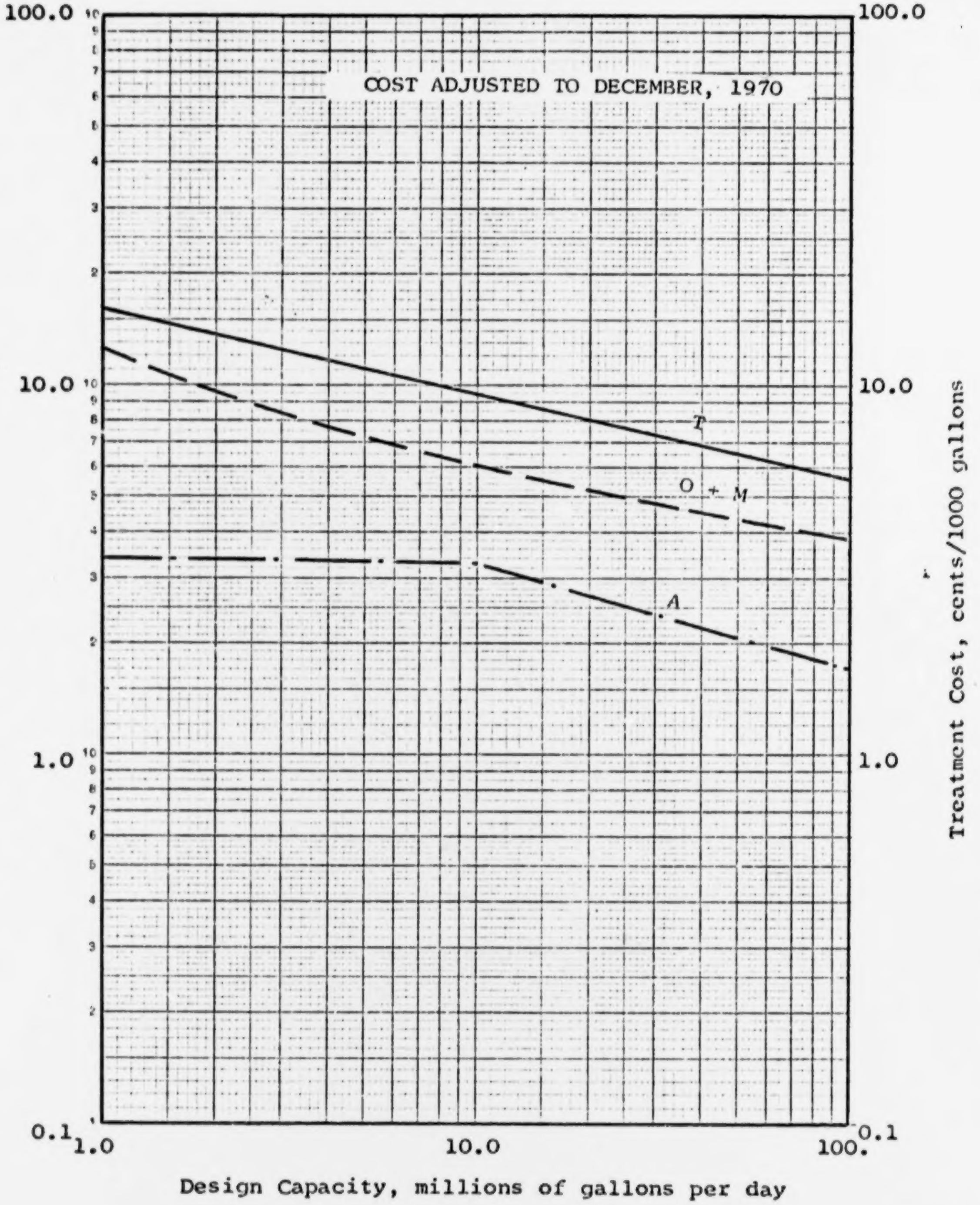
ALUM ADDITION TO AERATOR FOR PHOSPHORUS REMOVAL



A = Debt Service, cents per 1000 gallons (6% - 25 yr.)
T = Total Treatment Cost, cents per 1000 gallons

FIGURE 12

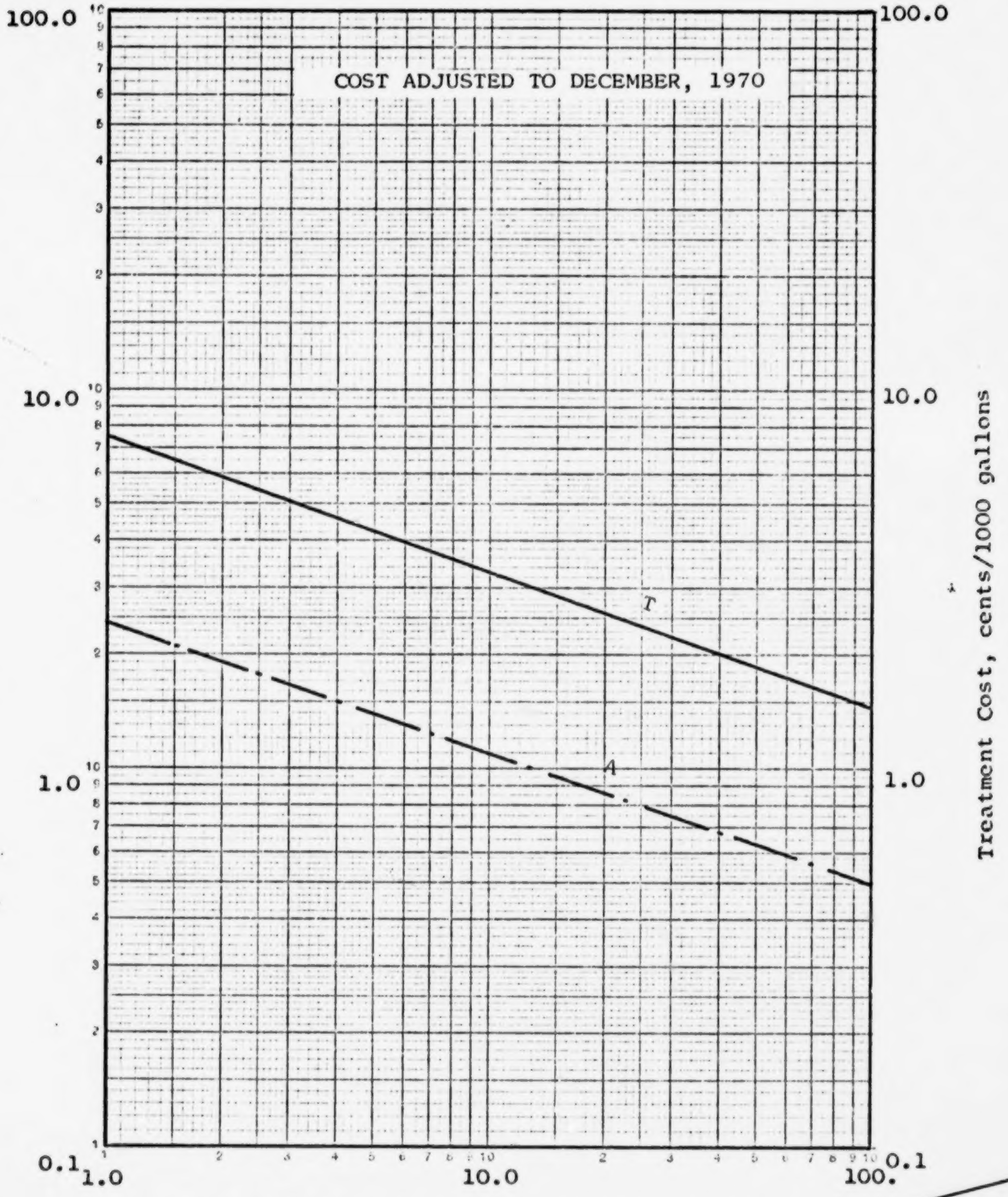
TWO-STAGE LIME CLARIFICATION



A = Debt Service, cents per 1000 gallons (6% - 25 yr.)
T = Total Treatment Cost, cents per 1000 gallons

FIGURE 13

MULTI-MEDIA FILTRATION



Design Capacity, millions of gallons per day

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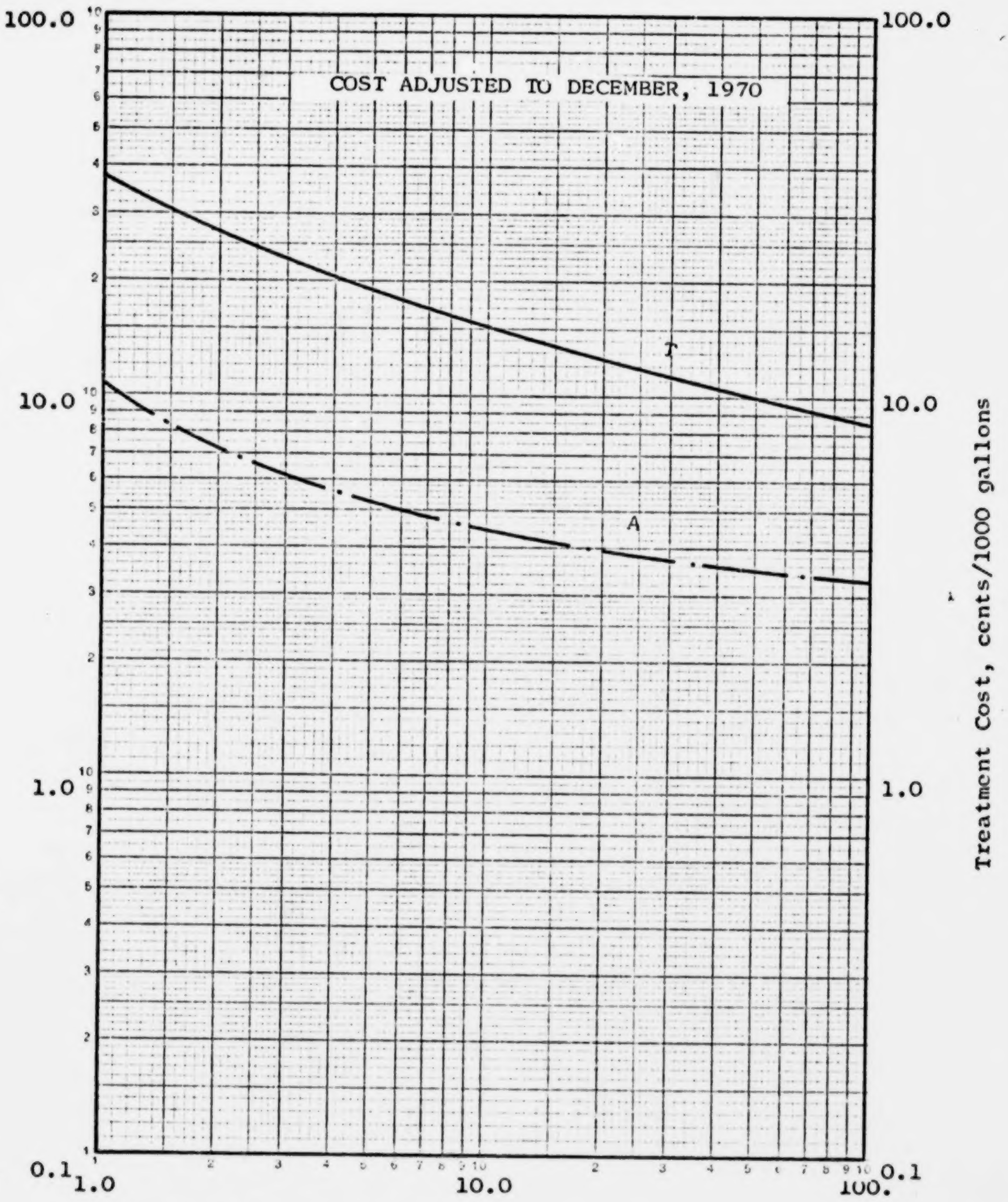
A = Debt Service, cents per 1000 gallons (6% - 25 yr.)
T = Total Treatment Cost, cents per 1000 gallons

FIGURE 14

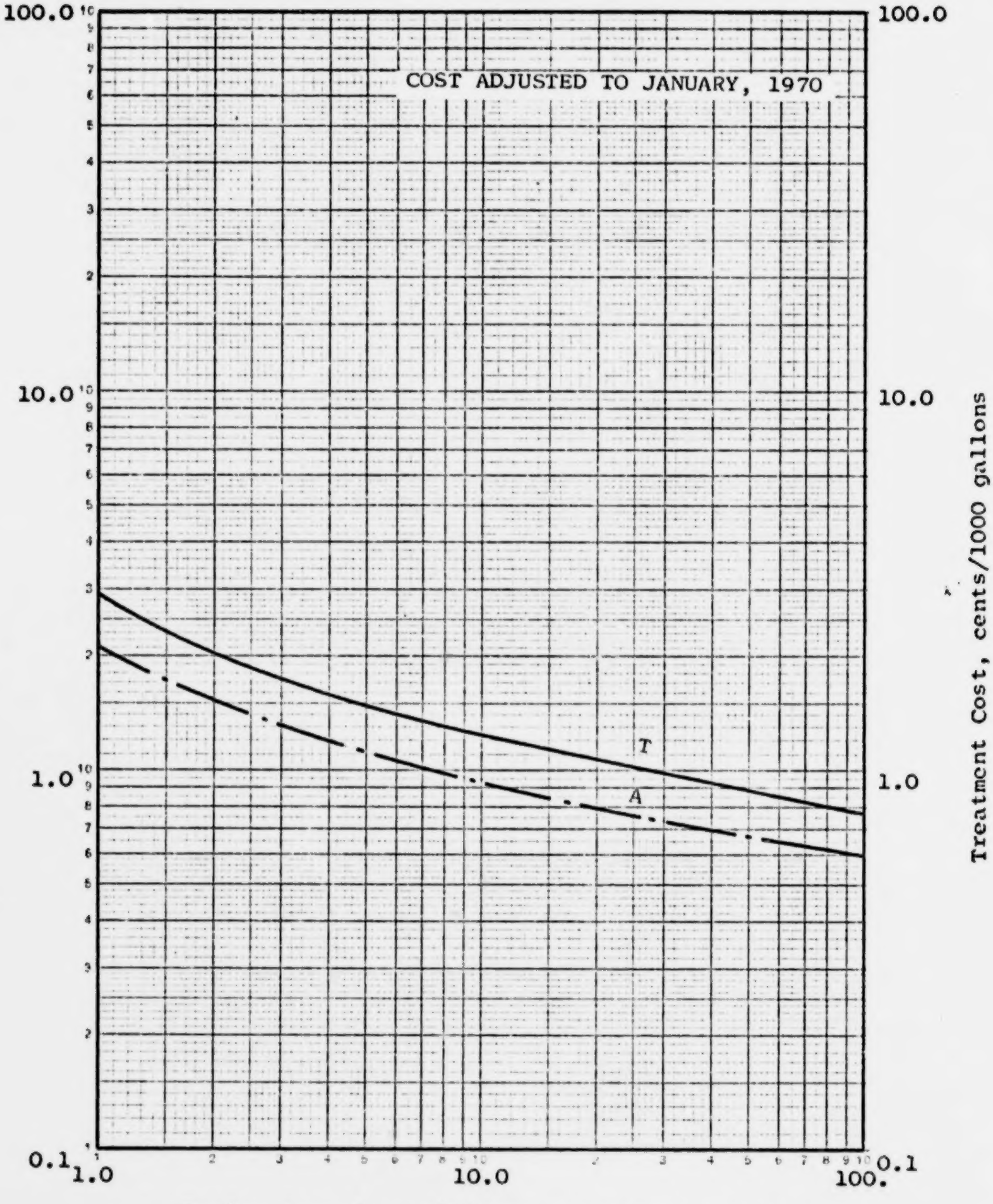
GRANULAR CARBON ADSORPTION



A = Debt Service, cents per 1000 gallons (6% - 25 yr.)
T = Total Treatment Cost, cents per 1000 gallons

FIGURE 15

RAW SEWAGE PUMPING AT THE PLANT



A = Debt Service, cents per 1000 gallons (6% - 25 yr.)
T = Total Treatment Cost, cents per 1000 gallons

FIGURE 16

FIGURE 17

```
              CASE 1     RSP & AS & SBEDS                                                  FORCE MAIN

            CONTRIBUTOR  RECEIVER   COMBINED    ECONOMIC    ECONOMIC     CONTRIBUTOR     RECEIVER      COMBINED
               PLANT      PLANT      PLANTS       PIPE        PIPE        TREATMENT     TREATMENT     TREATMENT
               FLOW       FLOW       FLOW        LENGTH     DIAMETER        COST          COST          COST
               MGD        MGD         MGD        MILES       INCHES     CTS/1000 GAL  CTS/1000 GAL  CTS/1000 GAL

                1.000      1.000      2.000      11.672      14.197        38.665        38.665       24.459
                1.000      2.000      3.000      12.209      14.197        38.665        25.096       19.837
                1.000      5.000      6.000      13.027      14.197        38.665        15.949       14.607
                1.000     10.000     11.000      13.581      14.197        38.665        12.186       11.709
                1.000     20.000     21.000      14.047      14.197        38.665         9.789        9.615
                1.000     40.000     41.000      14.439      14.197        38.665         8.168        8.102
                1.000     60.000     61.000      14.645      14.197        38.665         7.442        7.404
                1.000    100.000    101.000      14.889      14.197        38.665         6.677        6.657
  TOTAL TREATMENT COST -  FORCE MAIN   1.735 CTS/1000 GAL/MILE   PUMPING STATION  8.157 CTS/1000 GAL   SLOPE = 0.005

                2.000      2.000      4.000       6.919      19.526        25.096        25.096       17.050
                2.000      5.000      7.000       7.849      19.526        25.096        15.949       13.611
                2.000     10.000     12.000       8.516      19.526        25.096        12.186       11.301
                2.000     20.000     22.000       9.098      19.526        25.096         9.789        9.454
                2.000     40.000     42.000       9.598      19.526        25.096         8.168        8.039
                2.000     60.000     62.000       9.863      19.526        25.096         7.442        7.366
                2.000    100.000    102.000      10.180      19.526        25.096         6.677        6.637
  TOTAL TREATMENT COST -  FORCE MAIN   1.330 CTS/1000 GAL/MILE   PUMPING STATION  6.885 CTS/1000 GAL   SLOPE = 0.005

                5.000      5.000     10.000       3.107      29.721        15.949        15.949       11.700
                5.000     10.000     15.000       3.863      29.721        15.949        12.186       10.365
                5.000     20.000     25.000       4.579      29.721        15.949         9.789        9.038
                5.000     40.000     45.000       5.229      29.721        15.949         8.168        7.862
                5.000     60.000     65.000       5.584      29.721        15.949         7.442        7.259
                5.000    100.000    105.000       6.012      29.721        15.949         6.677        6.580
  TOTAL TREATMENT COST -  FORCE MAIN   0.963 CTS/1000 GAL/MILE   PUMPING STATION  5.504 CTS/1000 GAL   SLOPE = 0.005

               10.000     10.000     20.000       1.325      40.823        12.186        12.186        9.352
               10.000     20.000     30.000       2.090      40.823        12.186         9.789        8.503
               10.000     40.000     50.000       2.834      40.823        12.186         8.168        7.606
               10.000     60.000     70.000       3.255      40.823        12.186         7.442        7.098
               10.000    100.000    110.000       3.774      40.823        12.186         6.677        6.491
  TOTAL TREATMENT COST -  FORCE MAIN   0.769 CTS/1000 GAL/MILE   PUMPING STATION  4.647 CTS/1000 GAL   SLOPE = 0.005

               20.000     20.000     40.000       0.165      56.056         9.789         9.789        7.775
               20.000     40.000     60.000       0.954      56.056         9.789         8.168        7.202
               20.000     60.000     80.000       1.426      56.056         9.789         7.442        6.825
               20.000    100.000    120.000       2.027      56.056         9.789         6.677        6.330
  TOTAL TREATMENT COST -  FORCE MAIN   0.625 CTS/1000 GAL/MILE   PUMPING STATION  3.924 CTS/1000 GAL   SLOPE = 0.005

               40.000     40.000     80.000       0.000      76.960         8.168         8.168        6.644
               40.000     60.000    100.000       0.000      76.960         8.168         7.442        6.412
               40.000    100.000    140.000       0.627      76.960         8.168         6.677        6.063
  TOTAL TREATMENT COST -  FORCE MAIN   0.516 CTS/1000 GAL/MILE   PUMPING STATION  3.314 CTS/1000 GAL   SLOPE = 0.005

               60.000     60.000    120.000       0.000      92.630         7.442         7.442        6.110
               60.000    100.000    160.000       0.000      92.630         7.442         6.677        5.849
  TOTAL TREATMENT COST -  FORCE MAIN   0.465 CTS/1000 GAL/MILE   PUMPING STATION  3.003 CTS/1000 GAL   SLOPE = 0.005

              100.000    100.000    200.000       0.000     116.975         6.677         6.677        5.519
  TOTAL TREATMENT COST -  FORCE MAIN   0.412 CTS/1000 GAL/MILE   PUMPING STATION  2.652 CTS/1000 GAL   SLOPE = 0.005
```

FIGURE 18

```
               CASE 1     RSP & AS & SBEDS
                                                                                     GRAVITY SEWER
         CONTRIBUTOR  RECEIVER   COMBINED    ECONOMIC    ECONOMIC   CONTRIBUTOR     RECEIVER       COMBINED
            PLANT      PLANT      PLANTS       PIPE        PIPE      TREATMENT      TREATMENT      TREATMENT
            FLOW       FLOW        FLOW       LENGTH     DIAMETER       COST           COST           COST
            MGD        MGD         MGD        MILES       INCHES    CTS/1000 GAL   CTS/1000 GAL   CTS/1000 GAL

               1.000      1.000      2.000     17.950      17.089       38.665         38.665         24.459
               1.000      2.000      3.000     18.539      17.089       38.665         25.096         19.837
               1.000      5.000      6.000     19.436      17.089       38.665         15.949         14.607
               1.000     10.000     11.000     20.043      17.089       38.665         12.186         11.709
               1.000     20.000     21.000     20.554      17.089       38.665          9.789          9.615
               1.000     40.000     41.000     20.784      17.089       38.665          8.168          8.102
               1.000     60.000     61.000     21.209      17.089       38.665          7.442          7.404
               1.000    100.000    101.000     21.478      17.089       38.665          6.677          6.657
TOTAL TREATMENT COST -    GRAVITY SEWER   1.582 CTS/1000 GAL/MILE    SLOPE = 0.005

               2.000      2.000      4.000     14.731      22.162       25.096         25.096         17.050
               2.000      5.000      7.000     15.863      22.162       25.096         15.949         13.611
               2.000     10.000     12.000     16.675      22.162       25.096         12.186         11.301
               2.000     20.000     22.000     17.384      22.162       25.096          9.789          9.454
               2.000     40.000     42.000     17.994      22.162       25.096          8.168          8.039
               2.000     60.000     62.000     18.317      22.162       25.096          7.442          7.366
               2.000    100.000    102.000     18.703      22.162       25.096          6.677          6.637
TOTAL TREATMENT COST -    GRAVITY SEWER   1.092 CTS/1000 GAL/MILE    SLOPE = 0.005

               5.000      5.000     10.000     12.553      31.249       15.949         15.949         11.700
               5.000     10.000     15.000     13.628      31.249       15.949         12.186         10.365
               5.000     20.000     25.000     14.647      31.249       15.949          9.789          9.038
               5.000     40.000     45.000     15.573      31.249       15.949          8.168          7.862
               5.000     60.000     65.000     16.077      31.249       15.949          7.442          7.259
               5.000    100.000    105.000     16.687      31.249       15.949          6.677          6.580
TOTAL TREATMENT COST -    GRAVITY SEWER   0.676 CTS/1000 GAL/MILE    SLOPE = 0.005

              10.000     10.000     20.000     11.942      40.525       12.186         12.186          9.352
              10.000     20.000     30.000     13.182      40.525       12.186          9.789          8.503
              10.000     40.000     50.000     14.389      40.525       12.186          8.168          7.606
              10.000     60.000     70.000     15.071      40.525       12.186          7.442          7.098
              10.000    100.000    110.000     15.913      40.525       12.186          6.677          6.491
TOTAL TREATMENT COST -    GRAVITY SEWER   0.474 CTS/1000 GAL/MILE    SLOPE = 0.005

              20.000     20.000     40.000     12.053      52.554        9.789          9.789          7.775
              20.000     40.000     60.000     13.529      52.554        9.789          8.168          7.202
              20.000     60.000     80.000     14.411      52.554        9.789          7.442          6.825
              20.000    100.000    120.000     15.535      52.554        9.789          6.677          6.330
TOTAL TREATMENT COST -    GRAVITY SEWER   0.334 CTS/1000 GAL/MILE    SLOPE = 0.005

              40.000     40.000     80.000     12.903      68.154        8.168          8.168          6.644
              40.000     60.000    100.000     13.974      68.154        8.168          7.442          6.412
              40.000    100.000    140.000     15.406      68.154        8.168          6.677          6.063
TOTAL TREATMENT COST -    GRAVITY SEWER   0.236 CTS/1000 GAL/MILE    SLOPE = 0.005

              60.000     60.000    120.000     13.800      79.347        7.442          7.442          6.110
              60.000    100.000    160.000     15.402      79.347        7.442          6.677          5.849
TOTAL TREATMENT COST -    GRAVITY SEWER   0.193 CTS/1000 GAL/MILE    SLOPE = 0.005

             100.000    100.000    200.000     15.445      96.100        6.677          6.677          5.519
TOTAL TREATMENT COST -    GRAVITY SEWER   0.149 CTS/1000 GAL/MILE    SLOPE = 0.005
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FIGURE 19

```
       CASE 2     RSP & AS & SBEDS                                               FORCE MAIN

            CONTRIBUTOR  RECEIVER   COMBINED    ECONOMIC    ECONOMIC    CONTRIBUTOR   RECEIVER    COMBINED
               PLANT       PLANT     PLANTS       PIPE        PIPE       TREATMENT    TREATMENT   TREATMENT
               FLOW        FLOW       FLOW       LENGTH     DIAMETER       COST         COST        COST
               MGD         MGD        MGD        MILES       INCHES    CTS/1000 GAL CTS/1000 GAL CTS/1000 GAL

                1.000       1.000      2.000      14.533      14.197       38.665      44.904      25.096
                1.000       2.000      3.000      14.805      14.197       38.665      27.928      20.224
                1.000       5.000      6.000      15.256      14.197       38.665      16.925      14.777
                1.000      10.000     11.000      15.580      14.197       38.665      12.624      11.792
                1.000      20.000     21.000      15.871      14.197       38.665       9.989       9.655
                1.000      40.000     41.000      16.136      14.197       38.665       8.261       8.120
                1.000      60.000     61.000      16.285      14.197       38.665       7.501       7.415
                1.000     100.000    101.000      16.471      14.197       38.665       6.711       6.663
TOTAL TREATMENT COST -    FORCE MAIN   1.735 CTS/1000 GAL/MILE    PUMPING STATION  8.157 CTS/1000 GAL    SLOPE = 0.005

                2.000       2.000      4.000      10.195      19.526       25.096      30.582      17.614
                2.000       5.000      7.000      10.713      19.526       25.096      17.874      13.897
                2.000      10.000     12.000      11.106      19.526       25.096      13.057      11.453
                2.000      20.000     22.000      11.470      19.526       25.096      10.188       9.530
                2.000      40.000     42.000      11.809      19.526       25.096       8.353       8.074
                2.000      60.000     62.000      12.001      19.526       25.096       7.560       7.389
                2.000     100.000    102.000      12.243      19.526       25.096       6.744       6.650
TOTAL TREATMENT COST -    FORCE MAIN   1.330 CTS/1000 GAL/MILE    PUMPING STATION  6.885 CTS/1000 GAL    SLOPE = 0.005

                5.000       5.000     10.000       6.927      29.721       15.949      20.598      12.186
                5.000      10.000     15.000       7.377      29.721       15.949      14.326      10.664
                5.000      20.000     25.000       7.830      29.721       15.949      10.777       9.202
                5.000      40.000     45.000       8.273      29.721       15.949       8.628       7.944
                5.000      60.000     65.000       8.531      29.721       15.949       7.736       7.313
                5.000     100.000    105.000       8.859      29.721       15.949       6.845       6.610
TOTAL TREATMENT COST -    FORCE MAIN   0.963 CTS/1000 GAL/MILE    PUMPING STATION  5.504 CTS/1000 GAL    SLOPE = 0.005

               10.000      10.000     20.000       5.624      40.823       12.186      16.368       9.789
               10.000      20.000     30.000       6.114      40.823       12.186      11.741       8.772
               10.000      40.000     50.000       6.626      40.823       12.186       9.061       7.753
               10.000      60.000     70.000       6.733      40.823       12.186       8.028       7.196
               10.000     100.000    110.000       7.332      40.823       12.186       7.013       6.548
TOTAL TREATMENT COST -    FORCE MAIN   0.769 CTS/1000 GAL/MILE    PUMPING STATION  4.647 CTS/1000 GAL    SLOPE = 0.005

               20.000      20.000     40.000       5.031      56.056        9.789      13.617       8.168
               20.000      40.000     60.000       5.582      56.056        9.789       9.975       7.442
               20.000      60.000     80.000       5.930      56.056        9.789       8.607       6.994
               20.000     100.000    120.000       6.394      56.056        9.789       7.346       6.433
TOTAL TREATMENT COST -    FORCE MAIN   0.625 CTS/1000 GAL/MILE    PUMPING STATION  3.924 CTS/1000 GAL    SLOPE = 0.005

               40.000      40.000     80.000       5.009      76.960        8.168      11.722       6.994
               40.000      60.000    100.000       5.376      76.960        8.168       9.743       6.677
               40.000     100.000    140.000       5.886      76.960        8.168       8.005       6.236
TOTAL TREATMENT COST -    FORCE MAIN   0.516 CTS/1000 GAL/MILE    PUMPING STATION  3.314 CTS/1000 GAL    SLOPE = 0.005

               60.000      60.000    120.000       5.222      92.630        7.442      10.859       6.433
               60.000     100.000    160.000       5.743      92.630        7.442       8.656       6.072
TOTAL TREATMENT COST -    FORCE MAIN   0.465 CTS/1000 GAL/MILE    PUMPING STATION  3.003 CTS/1000 GAL    SLOPE = 0.005

              100.000     100.000    200.000       5.694     116.975        6.677       9.936       5.807
TOTAL TREATMENT COST -    FORCE MAIN   0.412 CTS/1000 GAL/MILE    PUMPING STATION  2.652 CTS/1000 GAL    SLOPE = 0.005
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FIGURE 20

```
          CASE 2     RSP & AS & SBEDS                                                  GRAVITY SEWEP

              CONTRIBUTOR  RECEIVER    COMBINED    ECONOMIC     ECONOMIC    CONTRIBUTOR    RECEIVER      COMBINED
                 PLANT      PLANT       PLANTS       PIPE         PIPE       TREATMENT     TREATMENT     TREATMENT
                 FLOW       FLOW        FLOW        LENGTH      DIAMETER       COST          COST          COST
                 MGD        MGD         MGD         MILES        INCHES    CTS/1000 GAL  CTS/1000 GAL  CTS/1000 GAL

                 1.000      1.000       2.000       21.087       17.089       38.665        44.904        25.096
                 1.000      2.000       3.000       21.385       17.089       38.665        27.928        20.224
                 1.000      5.000       6.000       21.880       17.089       38.665        16.925        14.777
                 1.000     10.000      11.000       22.235       17.089       38.665        12.624        11.792
                 1.000     20.000      21.000       22.553       17.089       38.665         9.989         9.655
                 1.000     40.000      41.000       22.844       17.089       38.665         8.261         8.120
                 1.000     60.000      61.000       23.007       17.089       38.665         7.501         7.415
                 1.000    100.000     101.000       23.712       17.089       38.665         6.711         6.663
TOTAL TREATMENT COST -    GRAVITY SEWER   1.582 CTS/1000 GAL/MILE    SLOPE = 0.005

                 2.000      2.000       4.000       18.721       22.162       25.096        30.582        17.614
                 2.000      5.000       7.000       19.352       22.162       25.096        17.874        13.897
                 2.000     10.000      12.000       19.830       22.162       25.096        13.057        11.453
                 2.000     20.000      22.000       20.273       22.162       25.096        10.188         9.530
                 2.000     40.000      42.000       20.686       22.162       25.096         8.353         8.074
                 2.000     60.000      62.000       20.920       22.162       25.096         7.560         7.389
                 2.000    100.000     102.000       21.215       22.162       25.096         6.744         6.650
TOTAL TREATMENT COST -    GRAVITY SEWER   1.092 CTS/1000 GAL/MILE    SLOPE = 0.005

                 5.000      5.000      10.000       17.988       31.249       15.949        20.598        12.186
                 5.000     10.000      15.000       18.629       31.249       15.949        14.326        10.664
                 5.000     20.000      25.000       19.273       31.249       15.949        10.777         9.202
                 5.000     40.000      45.000       19.904       31.249       15.949         8.628         7.944
                 5.000     60.000      65.000       20.270       31.249       15.949         7.736         7.313
                 5.000    100.000     105.000       20.737       31.249       15.949         6.845         6.610
TOTAL TREATMENT COST -    GRAVITY SEWER   0.676 CTS/1000 GAL/MILE    SLOPE = 0.005

                10.000     10.000      20.000       18.912       40.525       12.186        16.368         9.789
                10.000     20.000      30.000       19.707       40.525       12.186        11.741         8.772
                10.000     40.000      50.000       20.536       40.525       12.186         9.081         7.753
                10.000     60.000      70.000       21.035       40.525       12.186         8.028         7.196
                10.000    100.000     110.000       21.682       40.525       12.186         7.013         6.548
TOTAL TREATMENT COST -    GRAVITY SEWER   0.474 CTS/1000 GAL/MILE    SLOPE = 0.005

                20.000     20.000      40.000       21.153       52.554        9.789        13.617         8.168
                20.000     40.000      60.000       22.183       52.554        9.789         9.975         7.442
                20.000     60.000      80.000       22.834       52.554        9.789         8.607         6.994
                20.000    100.000     120.000       23.703       52.554        9.789         7.346         6.433
TOTAL TREATMENT COST -    GRAVITY SEWER   0.334 CTS/1000 GAL/MILE    SLOPE - 0.005

                40.000     40.000      80.000       24.985       68.154        8.168        11.722         6.994
                40.000     60.000     100.000       25.787       68.154        8.168         9.743         6.677
                40.000    100.000     140.000       26.903       68.154        8.168         8.005         6.236
TOTAL TREATMENT COST -    GRAVITY SEWER   0.236 CTS/1000 GAL/MILE    SLOPE = 0.005

                60.000     60.000     120.000       28.147       79.347        7.442        10.859         6.433
                60.000    100.000     160.000       29.404       79.347        7.442         8.656         6.072
TOTAL TREATMENT COST -    GRAVITY SEWER   0.193 CTS/1000 GAL/MILE    SLOPE = 0.005

               100.000    100.000     200.000       33.338       96.100        6.677         9.936         5.807
TOTAL TREATMENT COST -    GRAVITY SEWER   0.149 CTS/1000 GAL/MILE    SLOPE = 0.005
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FIGURE 21

```
            CASE 3     RSP & AS & SBEDS                                          FORCE MAIN

       CONTRIBUTOR  RECEIVER   COMBINED    ECONOMIC    ECONOMIC    CONTRIBUTOR   RECEIVER    COMBINED
          PLANT      PLANT      PLANTS       PIPE        PIPE       TREATMENT    TREATMENT   TREATMENT
          FLOW       FLOW        FLOW       LENGTH     DIAMETER        COST         COST        COST
           MGD        MGD         MGD        MILES      INCHES     CTS/1000 GAL CTS/1000 GAL CTS/1000 GAL

            1.000      1.000      2.000      4.834      14.197       38.665       38.665      30.392
            1.000      2.000      3.000      5.090      14.197       38.665       25.096      23.955
            1.000      5.000      6.000      5.522      14.197       38.665       15.949      16.778
            1.000     10.000     11.000      5.833      14.197       38.665       12.186      12.931
            1.000     20.000     21.000      6.112      14.197       38.665        9.789      10.271
            1.000     40.000     41.000      6.366      14.197       38.665        8.168       8.444
            1.000     60.000     61.000      6.509      14.197       38.665        7.442       7.635
            1.000    100.000    101.000      6.687      14.197       38.665        6.677       6.798
TOTAL TREATMENT COST -  FORCE MAIN  1.735 CTS/1000 GAL/MILE   PUMPING STATION  8.157 CTS/1000 GAL   SLOPE = 0.005

            2.000      2.000      4.000      1.979      19.526       25.096       25.096      20.336
            2.000      5.000      7.000      2.474      19.526       25.096       15.949      15.654
            2.000     10.000     12.000      2.851      19.526       25.096       12.186      12.557
            2.000     20.000     22.000      3.200      19.526       25.096        9.789      10.168
            2.000     40.000     42.000      3.525      19.526       25.096        8.168       8.423
            2.000     60.000     62.000      3.710      19.526       25.096        7.442       7.630
            2.000    100.000    102.000      3.941      19.526       25.096        6.677       6.800
TOTAL TREATMENT COST -  FORCE MAIN  1.330 CTS/1000 GAL/MILE   PUMPING STATION  6.885 CTS/1000 GAL   SLOPE = 0.005

            5.000      5.000     10.000      0.000      29.721       15.949       15.949      13.337
            5.000     10.000     15.000      0.140      29.721       15.949       12.186      11.560
            5.000     20.000     25.000      0.574      29.721       15.949        9.789       9.810
            5.000     40.000     45.000      1.000      29.721       15.949        8.168       8.314
            5.000     60.000     65.000      1.246      29.721       15.949        7.442       7.581
            5.000    100.000    105.000      1.560      29.721       15.949        6.677       6.785
TOTAL TREATMENT COST -  FORCE MAIN  0.963 CTS/1000 GAL/MILE   PUMPING STATION  5.504 CTS/1000 GAL   SLOPE = 0.005

           10.000     10.000     20.000      0.000      40.823       12.186       12.186      10.367
           10.000     20.000     30.000      0.000      40.823       12.186        9.789       9.255
           10.000     40.000     50.000      0.000      40.823       12.186        8.168       8.097
           10.000     60.000     70.000      0.000      40.823       12.186        7.442       7.462
           10.000    100.000    110.000      0.322      40.823       12.186        6.677       6.733
TOTAL TREATMENT COST -  FORCE MAIN  0.769 CTS/1000 GAL/MILE   PUMPING STATION  4.647 CTS/1000 GAL   SLOPE = 0.005

           20.000     20.000     40.000      0.000      56.056        9.789        9.789       8.426
           20.000     40.000     60.000      0.000      56.056        9.789        8.168       7.690
           20.000     60.000     80.000      0.000      56.056        9.789        7.442       7.213
           20.000    100.000    120.000      0.000      56.056        9.789        6.677       6.605
TOTAL TREATMENT COST -  FORCE MAIN  0.625 CTS/1000 GAL/MILE   PUMPING STATION  3.924 CTS/1000 GAL   SLOPE = 0.005

           40.000     40.000     80.000      0.000      76.960        8.168        8.168       7.073
           40.000     60.000    100.000      0.000      76.960        8.168        7.442       6.784
           40.000    100.000    140.000      0.000      76.960        8.168        6.677       6.353
TOTAL TREATMENT COST -  FORCE MAIN  0.516 CTS/1000 GAL/MILE   PUMPING STATION  3.314 CTS/1000 GAL   SLOPE = 0.005

           60.000     60.000    120.000      0.000      92.630        7.442        7.442       6.450
           60.000    100.000    160.000      0.000      92.630        7.442        6.677       6.133
TOTAL TREATMENT COST -  FORCE MAIN  0.465 CTS/1000 GAL/MILE   PUMPING STATION  3.003 CTS/1000 GAL   SLOPE = 0.005

          100.000    100.000    200.000      0.000     116.975        6.677        6.677       5.779
TOTAL TREATMENT COST -  FORCE MAIN  0.412 CTS/1000 GAL/MILE   PUMPING STATION  2.652 CTS/1000 GAL   SLOPE = 0.005
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FIGURE 22

```
              CASE 3     RSP & AS & SBEDS                                              GRAVITY SEWER

                  CONTRIBUTOR  RECEIVER     COMBINED     ECONOMIC      ECONOMIC      CONTRIBUTOR     RECEIVER       COMBINED
                     PLANT       PLANT       PLANTS        PIPE          PIPE         TREATMENT      TREATMENT      TREATMENT
                     FLOW        FLOW         FLOW        LENGTH       DIAMETER         COST           COST           COST
                      MGD         MGD          MGD        MILES         INCHES      CTS/1000 GAL   CTS/1000 GAL   CTS/1000 GAL

                     1.000       1.000        2.000       10.453        17.089          38.665         38.665         30.392
                     1.000       2.000        3.000       10.735        17.089          38.665         25.096         23.955
                     1.000       5.000        6.000       11.208        17.089          38.665         15.949         16.778
                     1.000      10.000       11.000       11.549        17.089          38.665         12.186         12.931
                     1.000      20.000       21.000       11.854        17.089          38.665          9.789         10.271
                     1.000      40.000       41.000       12.133        17.089          38.665          8.168          8.444
                     1.000      60.000       61.000       12.289        17.089          38.665          7.442          7.635
                     1.000     100.000      101.000       12.485        17.089          38.665          6.677          6.798
TOTAL TREATMENT COST -    GRAVITY SEWER    1.582 CTS/1000 GAL/MILE      SLOPE = 0.005

                     2.000       2.000        4.000        8.714        22.162          25.096         25.096         20.336
                     2.000       5.000        7.000        9.317        22.162          25.096         15.949         15.654
                     2.000      10.000       12.000        9.776        22.162          25.096         12.186         12.557
                     2.000      20.000       22.000       10.201        22.162          25.096          9.789         10.168
                     2.000      40.000       42.000       10.597        22.162          25.096          8.168          8.423
                     2.000      60.000       62.000       10.822        22.162          25.096          7.442          7.630
                     2.000     100.000      102.000       11.103        22.162          25.096          6.677          6.800
TOTAL TREATMENT COST -    GRAVITY SEWER    1.092 CTS/1000 GAL/MILE      SLOPE = 0.005

                     5.000       5.000       10.000        7.716        31.249          15.949         15.949         13.337
                     5.000      10.000       15.000        8.331        31.249          15.949         12.186         11.560
                     5.000      20.000       25.000        8.949        31.249          15.949          9.789          9.810
                     5.000      40.000       45.000        9.554        31.249          15.949          8.168          8.314
                     5.000      60.000       65.000        9.905        31.249          15.949          7.442          7.581
                     5.000     100.000      105.000       10.351        31.249          15.949          6.677          6.785
TOTAL TREATMENT COST -    GRAVITY SEWER    0.676 CTS/1000 GAL/MILE      SLOPE = 0.005

                    10.000      10.000       20.000        7.662        40.525          12.186         12.186         10.367
                    10.000      20.000       30.000        8.425        40.525          12.186          9.789          9.255
                    10.000      40.000       50.000        9.221        40.525          12.186          8.168          8.097
                    10.000      60.000       70.000        9.698        40.525          12.186          7.442          7.462
                    10.000     100.000      110.000       10.316        40.525          12.186          6.677          6.733
TOTAL TREATMENT COST -    GRAVITY SEWER    0.474 CTS/1000 GAL/MILE      SLOPE = 0.005

                    20.000      20.000       40.000        8.159        52.554           9.789          9.789          8.426
                    20.000      40.000       60.000        9.146        52.554           9.789          8.168          7.690
                    20.000      60.000       80.000        9.770        52.554           9.789          7.442          7.213
                    20.000     100.000      120.000       10.599        52.554           9.789          6.677          6.605
TOTAL TREATMENT COST -    GRAVITY SEWER    0.334 CTS/1000 GAL/MILE      SLOPE = 0.005

                    40.000      40.000       80.000        9.275        68.154           8.168          8.168          7.073
                    40.000      60.000      100.000       10.042        68.154           8.168          7.442          6.784
                    40.000     100.000      140.000       11.106        68.154           8.168          6.677          6.353
TOTAL TREATMENT COST -    GRAVITY SEWER    0.236 CTS/1000 GAL/MILE      SLOPE = 0.005

                    60.000      60.000      120.000       10.273        79.347           7.442          7.442          6.450
                    60.000     100.000      160.000       11.472        79.347           7.442          6.677          6.133
TOTAL TREATMENT COST -    GRAVITY SEWER    0.193 CTS/1000 GAL/MILE      SLOPE = 0.005

                   100.000     100.000      200.000       11.974        96.100           6.677          6.677          5.779
TOTAL TREATMENT COST -    GRAVITY SEWER    0.149 CTS/1000 GAL/MILE      SLOPE = 0.005
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FIGURE 23

```
              CASE 3     RSP & AS & SBEDS & LIME                                        FORCE MAIN

         CONTRIBUTOR  RECEIVER   COMBINED   ECONOMIC   ECONOMIC   CONTRIBUTOR   RECEIVER     COMBINED
            PLANT      PLANT      PLANTS      PIPE       PIPE      TREATMENT    TREATMENT    TREATMENT
            FLOW       FLOW       FLOW       LENGTH    DIAMETER      COST         COST         COST
            MGD        MGD        MGD        MILES      INCHES   CTS/1000 GAL CTS/1000 GAL CTS/1000 GAL

             1.000      1.000      2.000      7.468     14.197       54.636       54.636       44.077
             1.000      2.000      3.000      8.453     14.197       54.636       38.749       36.436
             1.000      5.000      6.000      9.834     14.197       54.636       27.033       27.429
             1.000     10.000     11.000     10.253     14.197       54.636       21.644       22.284
             1.000     20.000     21.000     10.897     14.197       54.636       17.854       18.316
             1.000     40.000     41.000     11.481     14.197       54.636       15.039       15.320
             1.000     60.000     61.000     11.800     14.197       54.636       13.696       13.898
             1.000    100.000    101.000     12.182     14.197       54.636       12.229       12.359
TOTAL TREATMENT COST -  FORCE MAIN  1.735 CTS/1000 GAL/MILE   PUMPING STATION   8.157 CTS/1000 GAL    SLOPE = 0.005

             2.000      2.000      4.000      4.925     19.526       38.749       38.749       32.029
             2.000      5.000      7.000      6.497     19.526       38.749       27.033       25.943
             2.000     10.000     12.000      6.931     19.526       38.749       21.644       21.810
             2.000     20.000     22.000      7.739     19.526       38.749       17.854       18.191
             2.000     40.000     42.000      8.487     19.526       38.749       15.039       15.303
             2.000     60.000     62.000      8.898     19.526       38.749       13.696       13.900
             2.000    100.000    102.000      9.393     19.526       38.749       12.229       12.369
TOTAL TREATMENT COST -  FORCE MAIN  1.330 CTS/1000 GAL/MILE   PUMPING STATION   6.885 CTS/1000 GAL    SLOPE = 0.005

             5.000      5.000     10.000      3.025     29.721       27.033       27.033       22.823
             5.000     10.000     15.000      3.273     29.721       27.033       21.644       20.554
             5.000     20.000     25.000      4.280     29.721       27.033       17.854       17.764
             5.000     40.000     45.000      5.256     29.721       27.033       15.039       15.198
             5.000     60.000     65.000      5.805     29.721       27.033       13.696       13.868
             5.000    100.000    105.000      6.475     29.721       27.033       12.229       12.375
TOTAL TREATMENT COST -  FORCE MAIN  0.963 CTS/1000 GAL/MILE   PUMPING STATION   5.504 CTS/1000 GAL    SLOPE = 0.005

            10.000     10.000     20.000      0.741     40.823       21.644       21.644       19.035
            10.000     20.000     30.000      1.831     40.823       21.644       17.854       17.098
            10.000     40.000     50.000      2.954     40.823       21.644       15.039       14.976
            10.000     60.000     70.000      3.607     40.823       21.644       13.696       13.771
            10.000    100.000    110.000      4.419     40.823       21.644       12.229       12.354
TOTAL TREATMENT COST -  FORCE MAIN  0.769 CTS/1000 GAL/MILE   PUMPING STATION   4.647 CTS/1000 GAL    SLOPE = 0.005

            20.000     20.000     40.000      0.340     56.056       17.854       17.854       15.785
            20.000     40.000     60.000      1.540     56.056       17.854       15.039       14.348
            20.000     60.000     80.000      2.274     56.056       17.854       13.696       13.399
            20.000    100.000    120.000      3.213     56.056       17.854       12.229       12.178
TOTAL TREATMENT COST -  FORCE MAIN  0.625 CTS/1000 GAL/MILE   PUMPING STATION   3.924 CTS/1000 GAL    SLOPE = 0.005

            40.000     40.000     80.000      0.245     76.960       15.039       15.039       13.318
            40.000     60.000    100.000      1.009     76.960       15.039       13.696       12.699
            40.000    100.000    140.000      2.029     76.960       15.039       12.229       11.786
TOTAL TREATMENT COST -  FORCE MAIN  0.516 CTS/1000 GAL/MILE   PUMPING STATION   3.314 CTS/1000 GAL    SLOPE = 0.005

            60.000     60.000    120.000      0.307     92.630       13.696       13.696       12.123
            60.000    100.000    160.000      1.340     92.630       13.696       12.229       11.419
TOTAL TREATMENT COST -  FORCE MAIN  0.465 CTS/1000 GAL/MILE   PUMPING STATION   3.003 CTS/1000 GAL    SLOPE = 0.005

           100.000    100.000    200.000      0.488    116.975       12.229       12.229       10.803
TOTAL TREATMENT COST -  FORCE MAIN  0.412 CTS/1000 GAL/MILE   PUMPING STATION   2.652 CTS/1000 GAL    SLOPE = 0.005
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FIGURE 24

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             CASE 3     RSP & AS & SBEDS & LIME                                          GRAVITY SEWER

          CONTRIBUTOR  RECEIVER    COMBINED    ECONOMIC    ECONOMIC     CONTRIBUTOR     RECEIVER       COMBINED
             PLANT      PLANT       PLANTS       PIPE        PIPE        TREATMENT      TREATMENT      TREATMENT
             FLOW       FLOW        FLOW        LENGTH     DIAMETER        COST           COST            COST
              MGD        MGD         MGD        MILES       INCHES     CTS/1000 GAL   CTS/1000 GAL   CTS/1000 GAL

                1.000      1.000       2.000      13.341      17.089         54.636         54.636         44.077
                1.000      2.000       3.000      14.421      17.089         54.636         38.749         36.436
                1.000      5.000       6.000      15.935      17.089         54.636         27.033         27.429
                1.000     10.000      11.000      16.395      17.089         54.636         21.644         22.284
                1.000     20.000      21.000      17.100      17.089         54.636         17.854         18.316
                1.000     40.000      41.000      17.741      17.089         54.636         15.039         15.320
                1.000     60.000      61.000      18.090      17.089         54.636         13.696         13.898
                1.000    100.000     101.000      18.510      17.089         54.636         12.229         12.359
TOTAL TREATMENT COST -   GRAVITY SEWER    1.582 CTS/1000 GAL/MILE     SLOPE = 0.005

                2.000      2.000       4.000      12.303      22.162         38.749         38.749         32.029
                2.000      5.000       7.000      14.217      22.162         38.749         27.033         25.943
                2.000     10.000      12.000      14.745      22.162         38.749         21.644         21.810
                2.000     20.000      22.000      15.730      22.162         38.749         17.854         18.191
                2.000     40.000      42.000      16.640      22.162         38.749         15.039         15.303
                2.000     60.000      62.000      17.141      22.162         38.749         13.696         13.900
                2.000    100.000     102.000      17.744      22.162         38.749         12.229         12.369
TOTAL TREATMENT COST -   GRAVITY SEWER    1.092 CTS/1000 GAL/MILE     SLOPE = 0.005

                5.000      5.000      10.000      12.436      31.249         27.033         27.033         22.823
                5.000     10.000      15.000      12.790      31.249         27.033         21.644         20.554
                5.000     20.000      25.000      14.222      31.249         27.033         17.854         17.764
                5.000     40.000      45.000      15.610      31.249         27.033         15.039         15.198
                5.000     60.000      65.000      16.392      31.249         27.033         13.696         13.868
                5.000    100.000     105.000      17.346      31.249         27.033         12.229         12.375
TOTAL TREATMENT COST -   GRAVITY SEWER    0.676 CTS/1000 GAL/MILE     SLOPE = 0.005

               10.000     10.000      20.000      10.995      40.525         21.644         21.644         19.035
               10.000     20.000      30.000      12.763      40.525         21.644         17.854         17.098
               10.000     40.000      50.000      14.583      40.525         21.644         15.039         14.976
               10.000     60.000      70.000      15.643      40.525         21.644         13.696         13.771
               10.000    100.000     110.000      16.958      40.525         21.644         12.229         12.354
TOTAL TREATMENT COST -   GRAVITY SEWER    0.474 CTS/1000 GAL/MILE     SLOPE = 0.005

               20.000     20.000      40.000      12.379      52.554         17.854         17.854         15.785
               20.000     40.000      60.000      14.624      52.554         17.854         15.039         14.348
               20.000     60.000      80.000      15.997      52.554         17.854         13.696         13.399
               20.000    100.000     120.000      17.753      52.554         17.854         12.229         12.178
TOTAL TREATMENT COST -   GRAVITY SEWER    0.334 CTS/1000 GAL/MILE     SLOPE = 0.005

               40.000     40.000      80.000      14.569      68.154         15.039         15.039         13.318
               40.000     60.000     100.000      16.239      68.154         15.039         13.696         12.699
               40.000    100.000     140.000      18.471      68.154         15.039         12.229         11.786
TOTAL TREATMENT COST -   GRAVITY SEWER    0.236 CTS/1000 GAL/MILE     SLOPE = 0.005

               60.000     60.000     120.000      16.296      79.347         13.696         13.696         12.123
               60.000    100.000     160.000      18.786      79.347         13.696         12.229         11.419
TOTAL TREATMENT COST -   GRAVITY SEWER    0.193 CTS/1000 GAL/MILE     SLOPE = 0.005

              100.000    100.000     200.000      19.031      96.100         12.229         12.229         10.803
TOTAL TREATMENT COST -   GRAVITY SEWER    0.149 CTS/1000 GAL/MILE     SLOPE = 0.005
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FIGURE 25

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                 CASE 3     RSP & AS & SBEUS                                                    GRAVITY SEWER

            CONTRIBUTOR  RECEIVER    COMBINED    ECONOMIC    ECONOMIC    CONTRIBUTOR    RECEIVER      COMBINED
               PLANT      PLANT      PLANTS       PIPE        PIPE       TREATMENT     TREATMENT     TREATMENT
               FLOW       FLOW        FLOW       LENGTH      DIAMETER       COST          COST          COST
               MGD        MGD         MGD        MILES       INCHES    CTS/1000 GAL  CTS/1000 GAL  CTS/1000 GAL

               1.000      1.000       2.000       7.185      23.109        38.665        38.665        30.392
               1.000      2.000       3.000       7.378      23.109        38.665        25.096        23.955
               1.000      5.000       6.000       7.703      23.109        38.665        15.949        16.778
               1.000     10.000      11.000       7.938      23.109        38.665        12.186        12.931
               1.000     20.000      21.000       8.148      23.109        38.665         9.789        10.271
               1.000     40.000      41.000       8.339      23.109        38.665         8.168         8.444
               1.000     60.000      61.000       8.447      23.109        38.665         7.442         7.635
               1.000    100.000     101.000       8.581      23.109        38.665         6.677         6.798
TOTAL TREATMENT COST -   GRAVITY SEWER    2.302 CTS/1000 GAL/MILE     SLOPE = 0.001

               2.000      2.000       4.000       5.936      29.968        25.096        25.096        20.336
               2.000      5.000       7.000       6.347      29.968        25.096        15.949        15.654
               2.000     10.000      12.000       6.660      29.968        25.096        12.186        12.557
               2.000     20.000      22.000       6.950      29.968        25.096         9.789        10.168
               2.000     40.000      42.000       7.219      29.968        25.096         8.168         8.423
               2.000     60.000      62.000       7.372      29.968        25.096         7.442         7.630
               2.000    100.000     102.000       7.564      29.968        25.096         6.677         6.800
TOTAL TREATMENT COST -   GRAVITY SEWER    1.603 CTS/1000 GAL/MILE     SLOPE = 0.001

               5.000      5.000      10.000       5.209      42.256        15.949        15.949        13.337
               5.000     10.000      15.000       5.624      42.256        15.949        12.186        11.560
               5.000     20.000      25.000       6.042      42.256        15.949         9.789         9.810
               5.000     40.000      45.000       6.450      42.256        15.949         8.168         8.314
               5.000     60.000      65.000       6.687      42.256        15.949         7.442         7.581
               5.000    100.000     105.000       6.988      42.256        15.949         6.677         6.785
TOTAL TREATMENT COST -   GRAVITY SEWER    1.002 CTS/1000 GAL/MILE     SLOPE = 0.001

              10.000     10.000      20.000       5.146      54.800        12.186        12.186        10.367
              10.000     20.000      30.000       5.658      54.800        12.186         9.789         9.255
              10.000     40.000      50.000       6.193      54.800        12.186         8.168         8.097
              10.000     60.000      70.000       6.513      54.800        12.186         7.442         7.462
              10.000    100.000     110.000       6.928      54.800        12.186         6.677         6.733
TOTAL TREATMENT COST -   GRAVITY SEWER    0.706 CTS/1000 GAL/MILE     SLOPE = 0.001

              20.000     20.000      40.000       5.457      71.067         9.789         9.789         8.426
              20.000     40.000      60.000       6.118      71.067         9.789         8.168         7.690
              20.000     60.000      80.000       6.534      71.067         9.789         7.442         7.213
              20.000    100.000     120.000       7.089      71.067         9.789         6.677         6.605
TOTAL TREATMENT COST -   GRAVITY SEWER    0.499 CTS/1000 GAL/MILE     SLOPE = 0.001

              40.000     40.000      80.000       6.184      92.162         8.168         8.168         7.073
              40.000     60.000     100.000       6.695      92.162         8.168         7.442         6.784
              40.000    100.000     140.000       7.405      92.162         8.168         6.677         6.353
TOTAL TREATMENT COST -   GRAVITY SEWER    0.354 CTS/1000 GAL/MILE     SLOPE = 0.001

              60.000     60.000     120.000       6.839     107.297         7.442         7.442         6.450
              60.000    100.000     160.000       7.637     107.297         7.442         6.677         6.133
TOTAL TREATMENT COST -   GRAVITY SEWER    0.290 CTS/1000 GAL/MILE     SLOPE = 0.001

             100.000    100.000     200.000       7.958     129.951         6.677         6.677         5.779
TOTAL TREATMENT COST -   GRAVITY SEWER    0.225 CTS/1000 GAL/MILE     SLOPE = 0.001
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         CASE 3     RSP & AS & SBEDS                                                      FORCE MAIN                           FIGURE 26
          CONTRIBUTOR  RECEIVER   COMBINED    ECONOMIC    ECONOMIC      CONTRIBUTOR    RECEIVER       COMBINED
             PLANT      PLANT      PLANTS       PIPE        PIPE         TREATMENT     TREATMENT      TREATMENT
             FLOW       FLOW       FLOW        LENGTH     DIAMETER         COST          COST           COST
              MGD        MGD        MGD         MILES      INCHES     CTS/1000 GAL  CTS/1000 GAL   CTS/1000 GAL

             1.000      1.000      2.000       5.333      14.197        38.665        38.665         30.392
             1.000      2.000      3.000       5.617      14.197        38.665        25.096         23.955
             1.000      5.000      6.000       6.093      14.197        38.665        15.949         16.778
             1.000     10.000     11.000       6.436      14.197        38.665        12.186         12.931
             1.000     20.000     21.000       6.743      14.197        38.665         9.789         10.271
             1.000     40.000     41.000       7.024      14.197        38.665         8.168          8.444
             1.000     60.000     61.000       7.181      14.197        38.665         7.442          7.635
             1.000    100.000    101.000       7.378      14.197        38.665         6.677          6.798
TOTAL TREATMENT COST -  FORCE MAIN   1.572 CTS/1000 GAL/MILE   PUMPING STATION   8.157 CTS/1000 GAL   SLOPE = 0.000

             2.000      2.000      4.000       2.254      19.526        25.096        25.096         20.336
             2.000      5.000      7.000       2.819      19.526        25.096        15.949         15.654
             2.000     10.000     12.000       3.248      19.526        25.096        12.186         12.557
             2.000     20.000     22.000       3.646      19.526        25.096         9.789         10.168
             2.000     40.000     42.000       4.016      19.526        25.096         8.168          8.423
             2.000     60.000     62.000       4.226      19.526        25.096         7.442          7.630
             2.000    100.000    102.000       4.489      19.526        25.096         6.677          6.800
TOTAL TREATMENT COST -  FORCE MAIN   1.167 CTS/1000 GAL/MILE   PUMPING STATION   6.885 CTS/1000 GAL   SLOPE = 0.000

             5.000      5.000     10.000       0.000      29.721        15.949        15.949         13.337
             5.000     10.000     15.000       0.168      29.721        15.949        12.186         11.560
             5.000     20.000     25.000       0.691      29.721        15.949         9.789          9.610
             5.000     40.000     45.000       1.203      29.721        15.949         8.168          8.314
             5.000     60.000     65.000       1.499      29.721        15.949         7.442          7.581
             5.000    100.000    105.000       1.877      29.721        15.949         6.677          6.785
TOTAL TREATMENT COST -  FORCE MAIN   0.800 CTS/1000 GAL/MILE   PUMPING STATION   5.504 CTS/1000 GAL   SLOPE = 0.000

            10.000     10.000     20.000       0.000      40.823        12.186        12.186         10.367
            10.000     20.000     30.000       0.000      40.823        12.186         9.789          9.255
            10.000     40.000     50.000       0.000      40.823        12.186         8.168          8.097
            10.000     60.000     70.000       0.000      40.823        12.186         7.442          7.462
            10.000    100.000    110.000       0.408      40.823        12.186         6.677          6.733
TOTAL TREATMENT COST -  FORCE MAIN   0.606 CTS/1000 GAL/MILE   PUMPING STATION   4.647 CTS/1000 GAL   SLOPE = 0.000

            20.000     20.000     40.000       0.000      56.056         9.789         9.789          8.426
            20.000     40.000     60.000       0.000      56.056         9.789         8.168          7.690
            20.000     60.000     80.000       0.000      56.056         9.789         7.442          7.213
            20.000    100.000    120.000       0.000      56.056         9.789         6.677          6.605
TOTAL TREATMENT COST -  FORCE MAIN   0.462 CTS/1000 GAL/MILE   PUMPING STATION   3.924 CTS/1000 GAL   SLOPE = 0.000

            40.000     40.000     80.000       0.000      76.960         8.168         8.168          7.073
            40.000     60.000    100.000       0.000      76.960         8.168         7.442          6.784
            40.000    100.000    140.000       0.000      76.960         8.168         6.677          6.353
TOTAL TREATMENT COST -  FORCE MAIN   0.353 CTS/1000 GAL/MILE   PUMPING STATION   3.314 CTS/1000 GAL   SLOPE = 0.000

            60.000     60.000    120.000       0.000      92.630         7.442         7.442          6.450
            60.000    100.000    160.000       0.000      92.630         7.442         6.677          6.133
TOTAL TREATMENT COST -  FORCE MAIN   0.303 CTS/1000 GAL/MILE   PUMPING STATION   3.003 CTS/1000 GAL   SLOPE = 0.000

           100.000    100.000    200.000       0.000     116.975         6.677         6.677          5.779
TOTAL TREATMENT COST -  FORCE MAIN   0.249 CTS/1000 GAL/MILE   PUMPING STATION   2.652 CTS/1000 GAL   SLOPE = 0.000
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            CASE 3     RSP & TF & SBEDS & LIME & FILT & CARBON  REC. NO ADV.   FORCE MAIN                              FIGURE 27

           CONTRIBUTOR  RECEIVER   COMBINED    ECONOMIC    ECONOMIC     CONTRIBUTOR     RECEIVER      COMBINED
              PLANT      PLANT      PLANTS       PIPE        PIPE        TREATMENT      TREATMENT     TREATMENT
              FLOW       FLOW       FLOW        LENGTH     DIAMETER        COST           COST          COST
              MGD        MGD        MGD         MILES       INCHES     CTS/1000 GAL   CTS/1000 GAL  CTS/1000 GAL
               1.000      1.000      2.000      31.156      14.197        95.505         34.006        36.176
               1.000      2.000      3.000      31.417      14.197        95.505         22.830        27.865
               1.000      5.000      6.000      31.816      14.197        95.505         15.092        18.794
               1.000     10.000     11.000      32.102      14.197        95.505         11.855        14.128
               1.000     20.000     21.000      32.371      14.197        95.505          9.791        11.060
               1.000     40.000     41.000      32.637      14.197        95.505          8.412         9.085
               1.000     60.000     61.000      32.802      14.197        95.505          7.806         8.264
               1.000    100.000    101.000      33.029      14.197        95.505          7.182         7.461
TOTAL TREATMENT COST -   FORCE MAIN   1.572 CTS/1000 GAL/MILE    PUMPING STATION   8.157 CTS/1000 GAL   SLOPE = 0.000
               2.000      2.000      4.000      29.537      19.526        69.568         22.830        25.508
               2.000      5.000      7.000      30.008      19.526        69.568         15.092        18.676
               2.000     10.000     12.000      30.367      19.526        69.568         11.855        14.415
               2.000     20.000     22.000      30.715      19.526        69.568          9.791        11.338
               2.000     40.000     42.000      31.069      19.526        69.568          8.412         9.268
               2.000     60.000     62.000      31.288      19.526        69.568          7.806         8.397
               2.000    100.000    102.000      31.592      19.526        69.568          7.182         7.547
TOTAL TREATMENT COST -   FORCE MAIN   1.167 CTS/1000 GAL/MILE    PUMPING STATION   6.885 CTS/1000 GAL   SLOPE = 0.000
               5.000      5.000     10.000      28.740      29.721        49.329         15.092        17.954
               5.000     10.000     15.000      29.179      29.721        49.329         11.855        14.725
               5.000     20.000     25.000      29.641      29.721        49.329          9.791        11.852
               5.000     40.000     45.000      30.132      29.721        49.329          8.412         9.666
               5.000     60.000     65.000      30.445      29.721        49.329          7.806         8.702
               5.000    100.000    105.000      30.883      29.721        49.329          7.182         7.749
TOTAL TREATMENT COST -   FORCE MAIN   0.800 CTS/1000 GAL/MILE    PUMPING STATION   5.504 CTS/1000 GAL   SLOPE = 0.000
              10.000     10.000     20.000      28.775      40.823        39.695         11.855        14.720
              10.000     20.000     30.000      29.309      40.823        39.695          9.791        12.281
              10.000     40.000     50.000      29.915      40.823        39.695          8.412        10.108
              10.000     60.000     70.000      30.312      40.823        39.695          7.806         9.070
              10.000    100.000    110.000      30.875      40.823        39.695          7.182         8.012
TOTAL TREATMENT COST -   FORCE MAIN   0.606 CTS/1000 GAL/MILE    PUMPING STATION   4.647 CTS/1000 GAL   SLOPE = 0.000
              20.000     20.000     40.000      30.391      56.056        32.837          9.791        12.323
              20.000     40.000     60.000      31.100      56.056        32.837          8.412        10.450
              20.000     60.000     80.000      31.587      56.056        32.837          7.806         9.430
              20.000    100.000    120.000      32.295      56.056        32.837          7.182         8.314
TOTAL TREATMENT COST -   FORCE MAIN   0.462 CTS/1000 GAL/MILE    PUMPING STATION   3.924 CTS/1000 GAL   SLOPE = 0.000
              40.000     40.000     80.000      32.658      76.960        27.736          8.412        10.637
              40.000     60.000    100.000      33.227      76.960        27.736          7.806         9.748
              40.000    100.000    140.000      34.086      76.960        27.736          7.182         8.660
TOTAL TREATMENT COST -   FORCE MAIN   0.353 CTS/1000 GAL/MILE    PUMPING STATION   3.314 CTS/1000 GAL   SLOPE = 0.000
              60.000     60.000    120.000      34.302      92.630        25.310          7.806         9.858
              60.000    100.000    160.000      35.244      92.630        25.310          7.182         8.848
TOTAL TREATMENT COST -   FORCE MAIN   0.303 CTS/1000 GAL/MILE    PUMPING STATION   3.003 CTS/1000 GAL   SLOPE = 0.000
             100.000    100.000    200.000      36.765     116.975        22.675          7.182         9.015
TOTAL TREATMENT COST -   FORCE MAIN   0.249 CTS/1000 GAL/MILE    PUMPING STATION   2.652 CTS/1000 GAL   SLOPE = 0.000
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FIGURE 28

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        CASE 3     RSP & TF & SBEDS & LIME & FILT & CARBON  REC. NC ADV.   GRAVITY SEWER

          CONTRIBUTOR  RECEIVER   COMBINED   ECONOMIC   ECONOMIC   CONTRIBUTOR    RECEIVER      COMBINED
             PLANT      PLANT      PLANTS      PIPE       PIPE      TREATMENT     TREATMENT     TREATMENT
             FLOW       FLOW       FLOW       LENGTH    DIAMETER      COST          COST          COST
              MGD        MGD        MGD        MILES     INCHES    CTS/1000 GAL  CTS/1000 GAL  CTS/1000 GAL

             1.000      1.000      2.000     24.821     23.109      95.505        34.006        36.176
             1.000      2.000      3.000     25.000     23.109      95.505        22.830        27.865
             1.000      5.000      6.000     25.272     23.109      95.505        15.092        18.794
             1.000     10.000     11.000     25.468     23.109      95.505        11.855        14.128
             1.000     20.000     21.000     25.651     23.109      95.505         9.791        11.060
             1.000     40.000     41.000     25.833     23.109      95.505         8.412         9.085
             1.000     60.000     61.000     25.946     23.109      95.505         7.806         8.264
             1.000    100.000    101.000     26.101     23.109      95.505         7.182         7.461
 TOTAL TREATMENT COST -   GRAVITY SEWER   2.302 CTS/1000 GAL/MILE   SLOPE = 0.001

             2.000      2.000      4.000     25.809     29.968      69.568        22.830        25.508
             2.000      5.000      7.000     26.152     29.968      69.568        15.092        18.676
             2.000     10.000     12.000     26.413     29.968      69.568        11.855        14.415
             2.000     20.000     22.000     26.667     29.968      69.568         9.791        11.338
             2.000     40.000     42.000     26.924     29.968      69.568         8.412         9.268
             2.000     60.000     62.000     27.085     29.968      69.568         7.806         8.397
             2.000    100.000    102.000     27.306     29.968      69.568         7.182         7.547
 TOTAL TREATMENT COST -   GRAVITY SEWER   1.603 CTS/1000 GAL/MILE   SLOPE = 0.001

             5.000      5.000     10.000     28.438     42.256      49.329        15.092        17.954
             5.000     10.000     15.000     28.788     42.256      49.329        11.855        14.725
             5.000     20.000     25.000     29.157     42.256      49.329         9.791        11.852
             5.000     40.000     45.000     29.550     42.256      49.329         8.412         9.666
             5.000     60.000     65.000     29.800     42.256      49.329         7.806         8.702
             5.000    100.000    105.000     30.149     42.256      49.329         7.182         7.749
 TOTAL TREATMENT COST -   GRAVITY SEWER   1.002 CTS/1000 GAL/MILE   SLOPE = 0.001

            10.000     10.000     20.000     31.292     54.800      39.695        11.855        14.720
            10.000     20.000     30.000     31.751     54.800      39.695         9.791        12.281
            10.000     40.000     50.000     32.271     54.800      39.695         8.412        10.108
            10.000     60.000     70.000     32.612     54.800      39.695         7.806         9.070
            10.000    100.000    110.000     33.096     54.800      39.695         7.182         8.012
 TOTAL TREATMENT COST -   GRAVITY SEWER   0.706 CTS/1000 GAL/MILE   SLOPE = 0.001

            20.000     20.000     40.000     35.987     71.067      32.837         9.791        12.323
            20.000     40.000     60.000     36.643     71.067      32.837         8.412        10.450
            20.000     60.000     80.000     37.094     71.067      32.837         7.806         9.430
            20.000    100.000    120.000     37.750     71.067      32.837         7.182         8.314
 TOTAL TREATMENT COST -   GRAVITY SEWER   0.499 CTS/1000 GAL/MILE   SLOPE = 0.001

            40.000     40.000     80.000     41.979     92.162      27.736         8.412        10.637
            40.000     60.000    100.000     42.548     92.162      27.736         7.806         9.748
            40.000    100.000    140.000     43.406     92.162      27.736         7.182         8.660
 TOTAL TREATMENT COST -   GRAVITY SEWER   0.354 CTS/1000 GAL/MILE   SLOPE = 0.001

            60.000     60.000    120.000     46.197    107.297      25.310         7.806         9.858
            60.000    100.000    160.000     47.181    107.297      25.310         7.182         8.848
 TOTAL TREATMENT COST -   GRAVITY SEWER   0.290 CTS/1000 GAL/MILE   SLOPE = 0.001

           100.000    100.000    200.000     52.423    129.951      22.675         7.182         9.015
 TOTAL TREATMENT COST -   GRAVITY SEWER   0.225 CTS/1000 GAL/MILE   SLOPE = 0.001
```

TOTAL TREATMENT COST

Sheet 1

Figure No.	Treatment Processes Used at Contributor Plant Note: Enter Charts at Q_c = 2 mgd	Total Cost in cents/Kgal	Total Cost Multiplied by Q_c, mgd	Sub-totals	Ident. Symbols
16	Raw Sewage Pumping at the Plant	2.18	4.36	4.36	TC1
11	TRICKLING FILTER & S.B.	20.4	40.8		
				40.8	TC2
	Total			45.16	TC12

Figure No.	Treatment Processes Used at Receiving Plant Note: Enter Charts at Q_r = 10 mgd	Total Cost in cents/Kgal	Total Cost Multiplied by Q_r, mgd	Sub-totals	Ident. Symbols
16	Raw Sewage Pumping at the Plant	1.33	13.3	13.3	TR1
11	TRICKLING FILTER, S.B.	10.6	106.		
				106.	TR2
	Total			119.3	TR12

Figure No.	Treatment Processes Used at Combined Plant Note: Enter Charts at Q_t = 12 mgd	Total Cost in cents/Kgal	Total Cost Multiplied by Q_t, mgd	Sub-totals	Ident. Symbols
16	Raw Sewage Pumping at the Plant	1.275	15.3	15.3	TT1
11	TRICKLING FILTER S.B	10.1	111.1		
				111.1	TT2
	Total			126.4	TT12

DEBT SERVICE FOR CAPITAL EXPENDITURES

Sheet 2

Figure No.	Treatment Processes Used at Contributor Plant Note: Enter Charts at Q_c = 2 mgd	Debt Service in cents/Kgal	Debt Service Multiplied by Q_c, mgd	Sub-totals	Ident. Symbols
16	Raw Sewage Pumping at the Plant	1.64	3.3	3.3	AC1
11	TRICKLING FILTER, S.B.	16.3	32.6		
				32.6	AC2
	Total			35.9	AC12

Figure No.	Treatment Processes Used at Receiving Plant Note: Enter Charts at Q_r = 10 mgd	Debt Service in cents/Kgal	Debt Service Multiplied by Q_r, mgd	Sub-totals	Ident. Symbols
16	Raw Sewage Pumping at the Plant	.985	9.85	9.85	AR1
11	TRICKLING FILTER, SB	6.0	60.0		
				60.0	AR2
	Total			69.85	AR12

Figure No.	Treatment Processes Used at Combined Plant Note: Enter Charts at Q_t = 12 mgd	Debt Service in cents/Kgal	Debt Service Multiplied by Q_t, mgd	Sub-totals	Ident. Symbols
16	Raw Sewage Pumping at the Plant	.94	11.3	11.3	AT1
11	TRICKLING FILTER, SB	5.67	68.0		
				68.0	AT2
	Total			79.3	AT12

PIPELINE TRANSMISSION COST Note: Enter Charts at Q_c = 2 mgd Sheet 3

1	Slope = .005 ft/ft
4	Gravity Sewers 1.09 cents/Kgal/mile x Q_c 2 mgd = 2.18 CGS
7	Force Mains 1.33 cents/Kgal/mile x Q_c 2 mgd = 2.66 CFM
7	Pump Station 6.8 cents/Kgal x Q_c 2 mgd = 13.6 CPS

BREAKEVEN PIPELINE LENGTH, MILES Case I Enter Values from Sheet 1

TC12 45.16 TT12 126.4

TR12 119.3 CPS 13.6 (CPS = 0 for gravity sewers)

Total 164.5 minus Total 126.4 = 38.1 /CGS 2.18 = 17.5 Gravity Sewers Breakeven Length, miles

Total 164.5 minus Total 140 = 24.5 /CFM 2.66 = 9.2 Breakdown Length, miles for Force Mains

BREAKEVEN PIPELINE LENGTH, MILES Case II Enter Values from Sheets 1 and 2

TC12 45.16 AR12 69.85

TR12 119.3 TT12 126.4

AT12 79.3 CPS 13.6 (CPS = 0 for gravity sewers)

Total 243.8 minus Total 196.25 47.5 /CGS 2.18 = 21.8 Gravity Sewer Breakeven Length, miles

Total 243.8 minus Total 209.85 = 33.9 /CFM 2.66 = 12.7 Breakeven Length, miles of Force Mains

BREAKEVEN PIPELINE LENGTH, MILES Case III Enter Values from Sheets 1 and 2

TC12 45.16 TR1 13.3

TR12 119.3 AR2 60.0

AT2 68.0 AC2 32.6

TT2 111.1

CPS 13.6 (CPS = 0 for gravity sewers)

Total 232.5 minus Total 217.0 = 15.5 /CGS 2.18 = 7.1 Gravity Sewer Breakeven Length, miles

Total 232.5 minus Total 230.6 = 1.9 /CFM 2.66 = .71 Breakeven Length, miles of Force Mains

TOTAL TREATMENT COST

Sheet 1

Figure No.	Treatment Processes Used at Contributor Plant Note: Enter Charts at Q_c = 5 mgd	Total Cost in cents/Kgal	Total Cost Multiplied by Q_c, mgd	Sub-totals	Ident. Symbols
16	Raw Sewage Pumping at the Plant	1.58	7.90	7.90	TC1
8	ACTIVATED SLUDGE S.B.	14.4	72.0		
13	LIME CLARIFICATION	11.1	55.5		
14	FILTRATION	4.2	21.0		
				148.5	TC2
	Total			156.4	TC12

Figure No.	Treatment Processes Used at Receiving Plant Note: Enter Charts at Q_r = 60 mgd	Total Cost in cents/Kgal	Total Cost Multiplied by Q_r, mgd	Sub-totals	Ident. Symbols
16	Raw Sewage Pumping at the Plant	.91	54.6	54.6	TR1
8	ACTIVATED SLUDGE S.B	6.58	394.8		
13	LIME CLARIFICATION	6.2	372.		
14	FILTRATION	1.74	104.4		
				871.2	TR2
	Total			925.8	TR12

Figure No.	Treatment Processes Used at Combined Plant Note: Enter Charts at Q_t = 65 mgd	Total Cost in cents/Kgal	Total Cost Multiplied by Q_t, mgd	Sub-totals	Ident. Symbols
16	Raw Sewage Pumping at the Plant	.90	58.5	58.5	TT1
8	ACTIVATED SLUDGE S.B	6.47	420.6		
13	LIME CLARIFICATION	6.1	396.5		
14	FILTRATION	1.7	110.5		
				927.6	TT2
	Total			986.1	TT12

Figure No.	Treatment Processes Used at Contributor Plant Note: Enter Charts at Q_c = 5 mgd	Debt Servic in cents/Kgal	Debt Servic Multiplied by Q_c, mgd	Sub-totals	Ident. Symbols
16	Raw Sewage Pumping at the Plant	1.20	6.0	6.0	AC1
8	ACTIVATED SLUDGE SB	7.06	35.3		
13	LIME CLARIFICATION	3.4	17.0		
14	FILTRATION	1.4	7.0		
				59.3	AC2
	Total			65.3	AC12

Figure No.	Treatment Processes Used at Receiving Plant Note: Enter Charts at Q_r = 60 mgd	Debt Servic in cents/Kgal	Debt Servic Multiplied by Q_r, mgd	Sub-totals	Ident. Symbols
16	Raw Sewage Pumping at the Plant	.70	42.0	42.0	AR1
8	ACTIVATED SLUDGE S.B.	3.64	218.4		
13	LIME CLARIFICATION	2.1	126.0		
14	FILTRATION	0.6	36.		
				380.4	AR2
	Total			422.4	AR12

Figure No.	Treatment Processes Used at Combined Plant Note: Enter Charts at Q_t = 65 mgd	Debt Servic in cents/Kgal	Debt Servic Multiplied by Q_t, mgd	Sub-totals	Ident. Symbols
16	Raw Sewage Pumping at the Plant	.68	44.2	44.2	AT1
8	ACTIVATED SLUDGE SB	3.58	232.7		
13	LIME CLARIFICATION	1.90	123.5		
14	FILTRATION	.57	37.0		
				393.2	AT2
	Total			437.4	AT12

PIPELINE TRANSMISSION COST Note: Enter Charts at Q_c = 5 mgd Sheet 3

1	Slope = .001 ft/ft FOR SEWERS SLOPE = 0.00 FORCE MAINS
4	Gravity Sewers 1.02 cents/Kgal/mile x Q_c 5 mgd = 5.10 CGS
7	Force Mains .80 cents/Kgal/mile x Q_c 5 mgd = 4.0 CFM
7	Pump Station 5.6 cents/Kgal x Q_c 5 mgd = 28.0 CPS

BREAKEVEN PIPELINE LENGTH, MILES Case I Enter Values from Sheet 1

TC12 156.4 TT12 986.1

TR12 925.8 CPS 28. (CPS = 0 for gravity sewers)

Total 1082.2 minus Total 986.1 = 96.1 /CGS 5.1 = 18.8 Gravity Sewers Breakeven Length, miles

Total 1082.2 minus Total 1014.1 = 68.1 /CFM 4. = 17.0 Breakdown Length, miles for Force Mains

BREAKEVEN PIPELINE LENGTH, MILES Case II Enter Values from Sheets 1 and 2

TC12 156.4 AR12 422.4

TR12 925.8 TT12 986.1

AT12 437.4 CPS 28 (CPS = 0 for gravity sewers)

Total 1519.6 minus Total 1408.5 = 111.1 /CGS 5.1 = 21.8 Gravity Sewer Breakeven Length, miles

Total 1519.6 minus Total 1436.5 = 83.1 /CFM 4.0 = 20.8 Breakeven Length, miles of Force Mains

BREAKEVEN PIPELINE LENGTH, MILES Case III Enter Values from Sheets 1 and 2

TC12 156.4 TR1 54.6

TR12 925.8 AR2 380.4

AT2 393.2 AC2 59.3

TT2 927.6

CPS 28. (CPS = 0 for gravity sewers)

Total 1475.4 minus Total 1421.9 = 53.5 /CGS 5.1 = 10.5 Gravity Sewer Breakeven Length, miles

Total 1475.4 minus Total 1449.9 = 25.5 /CFM 4. = 6.4 Breakeven Length, miles of Force Mains

Figure No.	Treatment Processes Used at Contributor Plant Note: Enter Charts at Q_c = 1 mgd	Total Cost in cents/Kgal	Total Cost Multiplied by Q_c, mgd	Sub-totals	Ident. Symbols
16	Raw Sewage Pumping at the Plant	3.1	3.1	3.1	TC1
8	ACTIVATED SLUDGE, S.B.	35.3	35.3		
13	LIME CLARIFICATION	16.0	16.0		
14	FILTRATION	7.5	7.5		
15	CARBON ADSORPTION	37.5	37.5	96.3	TC2
	Total			99.4	TC12

Figure No.	Treatment Processes Used at Receiving Plant Note: Enter Charts at Q_r = 50 mgd	Total Cost in cents/Kgal	Total Cost Multiplied by Q_r, mgd	Sub-totals	Ident. Symbols
16	Raw Sewage Pumping at the Plant	.94	47.0	47.0	TR1
8	ACTIVATED SLUDGE, SB	6.90	345.0		
				345.	TR2
	Total			392.	TR12

Figure No.	Treatment Processes Used at Combined Plant Note: Enter Charts at Q_t = 51 mgd	Total Cost in cents/Kgal	Total Cost Multiplied by Q_t, mgd	Sub-totals	Ident. Symbols
16	Raw Sewage Pumping at the Plant	.93	47.4	47.4	TT1
8	ACTIVATED SLUDGE SB	6.79	346.3		
				346.3	TT2
	Total			393.7	TT12

DEBT SERVICE FOR CAPITAL EXPENDITURES

Sheet 2

Figure No.	Treatment Processes Used at Contributor Plant Note: Enter Charts at Q_c = 1 mgd	Debt Servic in cents/Kgal	Debt Servic Multiplied by Q_c, mgd	Sub-totals	Ident. Symbols
16	Raw Sewage Pumping at the Plant	2.25	2.25	2.25	AC1
8	ACTIVATED SLUDGE, S.B.	18.7	18.7		
13	LIME CLARIFICATION	3.4	3.4		
14	FILTRATION	2.4	2.4		
15	CARBON ADSORPTION	10.7	10.7	35.2	AC2
	Total			37.5	AC12

Figure No.	Treatment Processes Used at Receiving Plant Note: Enter Charts at Q_r = 50 mgd	Debt Servic in cents/Kgal	Debt Servic Multiplied by Q_r, mgd	Sub-totals	Ident. Symbols
16	Raw Sewage Pumping at the Plant	.72	36.0	36.0	AR1
8	ACTIVATED SLUDGE S.B.	3.75	187.5		
				187.5	AR2
	Total			223.5	AR12

Figure No.	Treatment Processes Used at Combined Plant Note: Enter Charts at Q_t = 51 mgd	Debt Servic in cents/Kgal	Debt Servic Multiplied by Q_t, mgd	Sub-totals	Ident. Symbols
16	Raw Sewage Pumping at the Plant	72	36.7	36.7	AT1
8	ACTIVATED SLUDGE. S.B.	3.75	191.3		
				191.3	AT2
	Total			228.0	AT12

PIPELINE TRANSMISSION COST   Note: Enter Charts at Q_c = 1 mgd   Sheet 3

1	Slope = .005 ft/ft
4	Gravity Sewers 1.58 cents/Kgal/mile x Q_c 1 mgd = 1.58 CGS
7	Force Mains 1.73 cents/Kgal/mile x Q_c 1 mgd = 1.73 [illegible]
7	Pump Station 8.2 cents/Kgal x Q_c 1 mgd = 8.2 CPS

BREAKEVEN PIPELINE LENGTH, MILES   Case I   Enter Values from Sheet 1

TC12 99.4   TT12 393.7
TR12 392.0   CPS 8.2 (CPS = 0 for gravity sewers)
Total 491.4 minus Total 393.7 = 97.7 /CGS 1.58 = 62 Gravity Sewers Breakeven Length, miles
Total 491.4 minus Total 401.9 = 89.5 /CFM 1.73 = 52 Breakdown Length, miles for Force Mains

BREAKEVEN PIPELINE LENGTH, MILES   Case II   Enter Values from Sheets 1 and 2

TC12 99.4   AR12 223.5
TR12 392.0   TT12 393.7
AT12 228.0   CPS 8.2 (CPS = 0 for gravity sewers)
Total 719.4 minus Total 617.2 = 102.2 /CGS 1.58 = 65 Gravity Sewer Breakeven Length, miles
Total 719.4 minus Total 625.4 = 94. /CFM 1.73 = 54 Breakeven Length, miles of Force Mains

BREAKEVEN PIPELINE LENGTH, MILES   Case III   Enter Values from Sheets 1 and 2

TC12 99.4   TR1 47.0
TR12 392.0   AR2 187.5
AT2 191.3   AC2 35.2
TT2 346.3
CPS 8.2 (CPS = 0 for gravity sewers)
Total 682.7 minus Total 616.0 = 66.7 /CGS 1.58 = 42 Gravity Sewer Breakeven Length, miles
Total 682.7 minus Total 624.2 = 58.5 /CFM 1.73 = 34 Breakeven Length, miles of Force Mains

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : Dr. William N. Fitch
Systems and Economics Branch

DATE: April 23, 1971

THRU : F. M. Middleton, Director of Research, AWTRL

FROM : Robert Smith and Richard G. Eilers
Treatment Optimization Research Program

SUBJECT: The Economic Advantages Associated with Staged Construction of Wastewater Treatment Plants

A short digital computer program has been written to examine the potential economic advantages of staged construction of wastewater treatment plants. The kind of plant used in this calculation is the activated sludge plant with primary sedimentation. Cost relationships for the activated sludge plant using anaerobic digesters and sludge drying beds for sludge disposal are shown in Figure 1. These cost relationships were derived from preliminary results of a Contract No. 14-12-462 with Black and Veatch Consulting Engineers, Kansas City, Missouri. The useful life for all plants was taken as 30 years.

A diagram of the kind of computation made is shown in Figure 2. The initial population was taken as 10,000, 100,000 and 1,000,000 corresponding to 1 mgd, 10 mgd, and 100 mgd. The population growth was assumed to be exponential with a growth rate of 0.01, 0.02, and 0.05. The relationship used is shown below.

```
POP = POPI*EXP(RPG*TC)
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The time increment (TI) for building stages was always taken as a multiple of 30 years. The incremental plant was sized to just meet the requirements of the growing population at the end of the time increment (TI). Each incremental plant was assumed to depreciate in a straight line over the thirty year period. For incremental plants built after the start of the 30 year period a credit was assumed to occur at the end of the 30 year period.

All expenditures and credits were converted to a present worth by dividing by the factor (1 + RI)**T where T is the time at which the expenditure or the credit occurred after the beginning of the 30 year period. All credits due to useful life remaining at the end of the 30 year period were taken at the end of the 30 year period.

5010-108

Buy U.S. Savings Bonds Regularly on the Payroll Savings Plan

Tables 1, 2 and 3 shows computed results for 1, 10 and 100 mgd activated sludge plants with sludge drying beds based on a design period (TT) of 30 years. Note that a 1 mgd plant is assumed to service a population of 10,000 (based on 100 gallons/day/person), etc. For interest yields (RI) of .04, .05 and .06, the rate of population growth (RPG) was varied as .01, .02 and .05 for time increments (TI) of 1, 2, 3, 5, 6, 10, 15 and 30 years. The RI = .06 output is plotted in Figures 3, 4 and 5. The program listing is given in Table 4

A similar calculation is underway for staged construction of interceptor sewers.

Bob Smith
Robert Smith

Richard G. Eilers
Richard G. Eilers

Attachments

DEFINITIONS

The following six parameters are input to the program:

RI	yield on municipal bonds to finance the plant, fraction
POPI	initial design population of the plant
TT	total plant design period, years
TI	time increment for addition of increased capacity to the plant, years
TC	cumulative time, years
RPG	rate of population growth, fraction of existing population

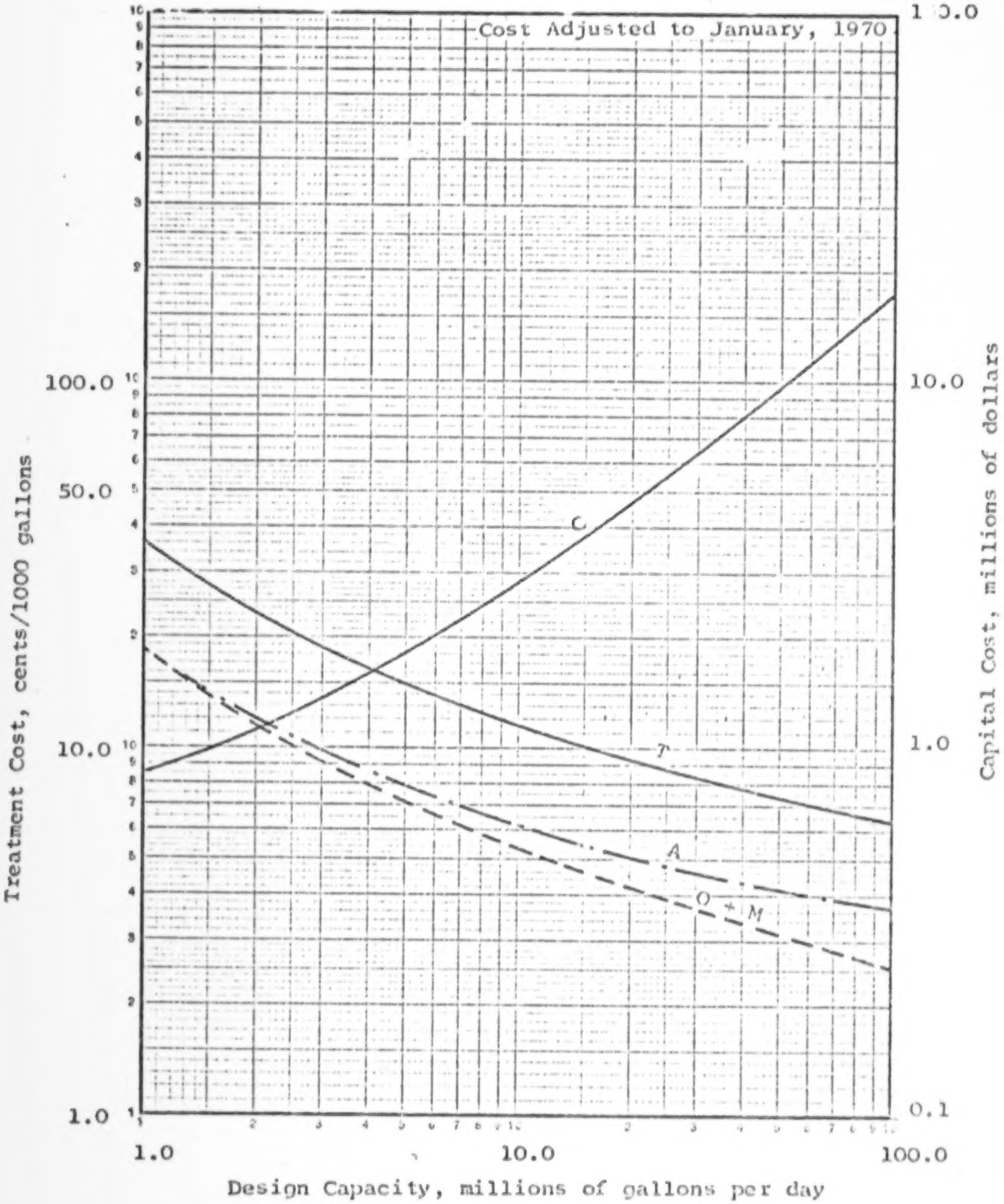
The following four parameters are computed and printed out by the program:

N	number of time increment additions to the plant
COOST	total construction cost of original plant and plant additions, dollars
SCOST	total salvage value of the plant additions at the end of the original design period of the plant, dollars
FCOST	COOST - SCOST

COOST, SCOST and FCOST are expressed as present worth dollars at the time beginning the design period of the original plant.

ACTIVATED SLUDGE PLANTS

Including: Raw Sewage Pumps, Preliminary Treatment-G+F+S, Primary Sedimentation, Primary Sludge Pumps, Aerators, Diffused Air System, Final Settlers-Multiple, Recirculation Pumps, Sludge Thickener, Anaerobic Digesters, Sludge Drying Beds, Chlorination, Laboratory



C = Capital Cost, millions of dollars
A = Debt Service, cents per 1000 gallons (6% - 25 yr.)
O + M = Operating and Maintenance Cost, cents per 1000 gallons
T = Total Treatment Cost, cents per 1000 gallons

FIGURE 1

K+E 10 X 10 TO ½ INCH 46 1320
KEUFFEL & ESSER CO.

DIAGRAM OF STAGED CONSTRUCTION OF WASTEWATER TREATMENT PLANTS

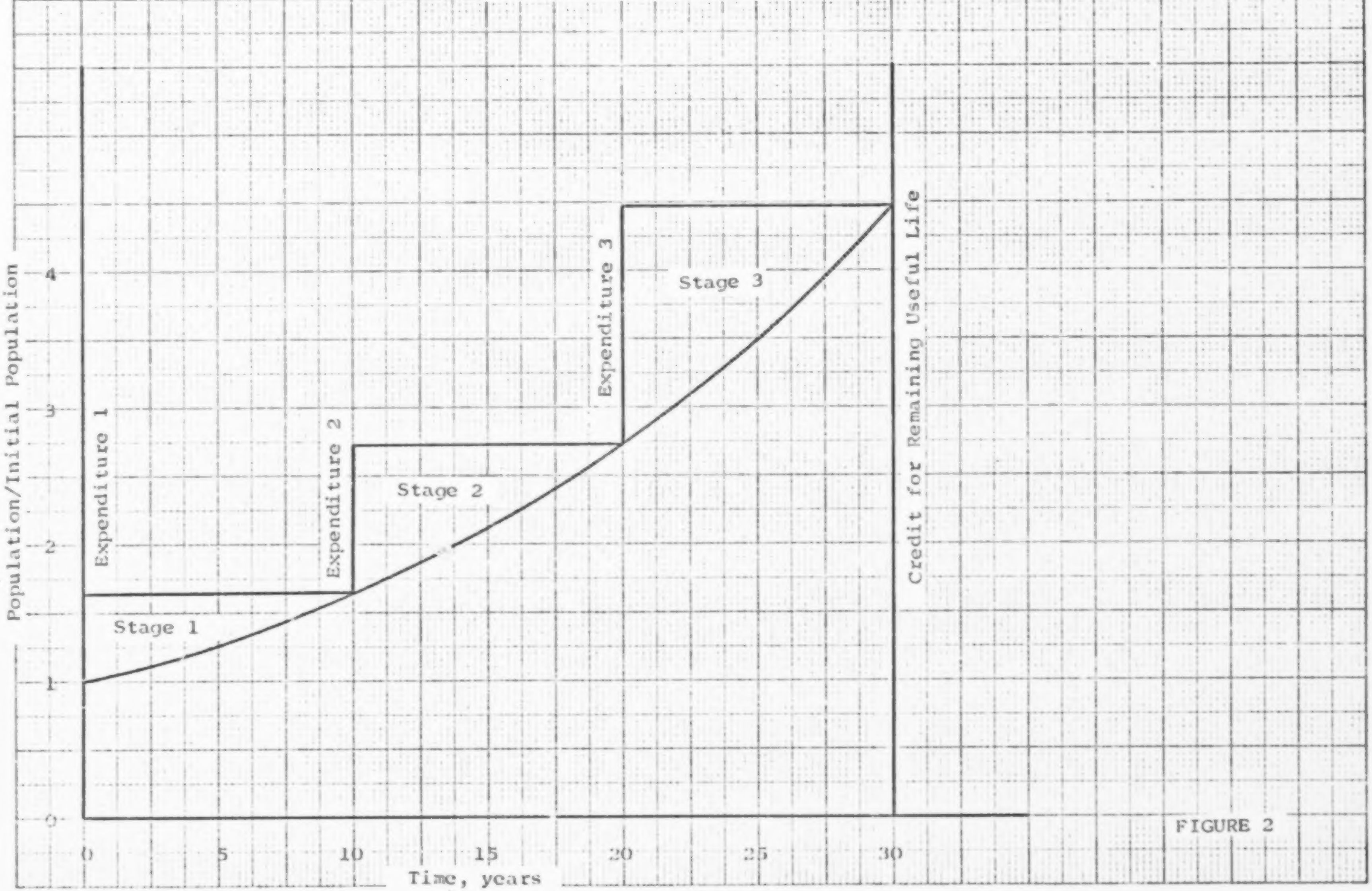


FIGURE 2

K&E 10 X 10 TO ½ INCH 46 1320
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

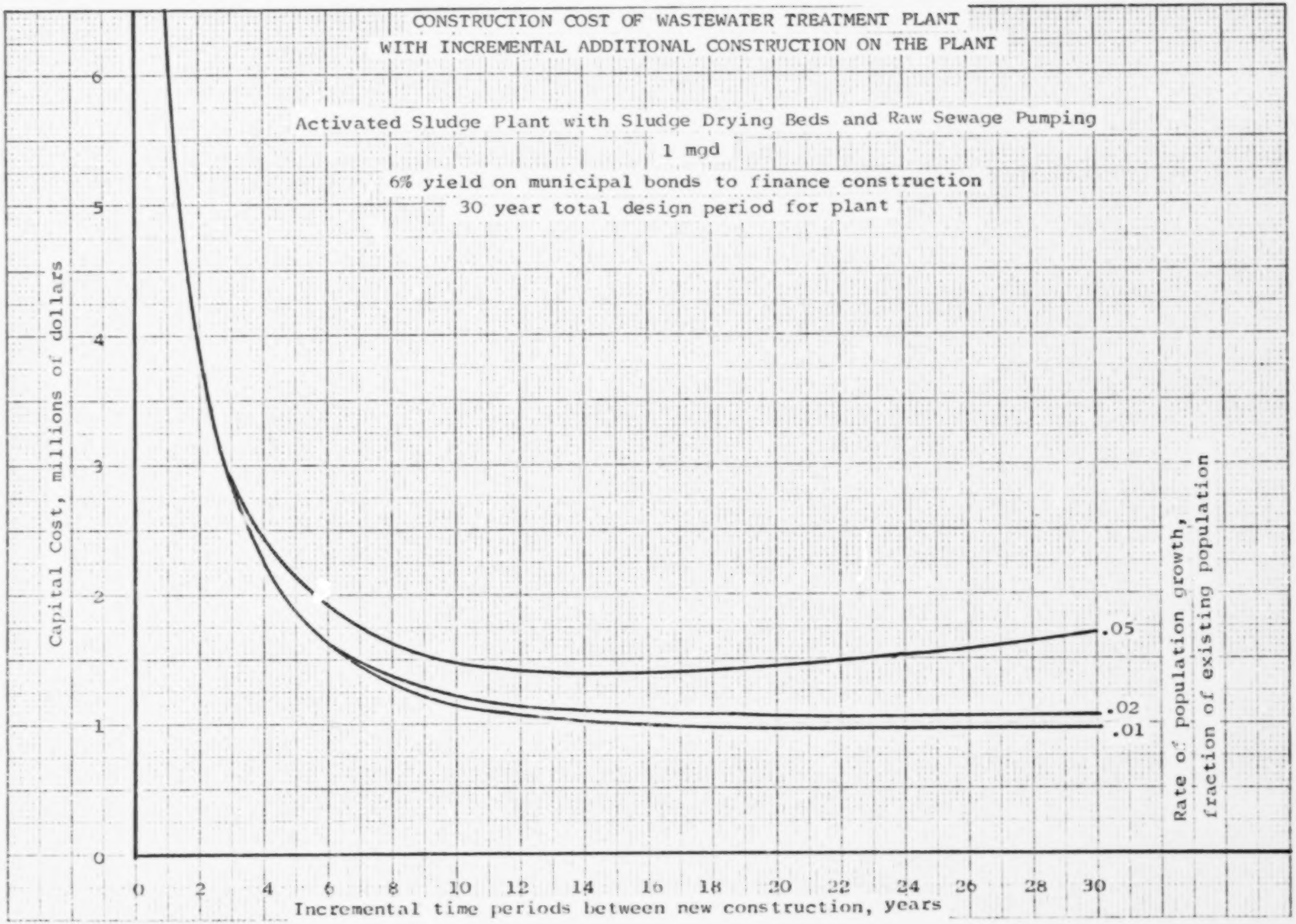
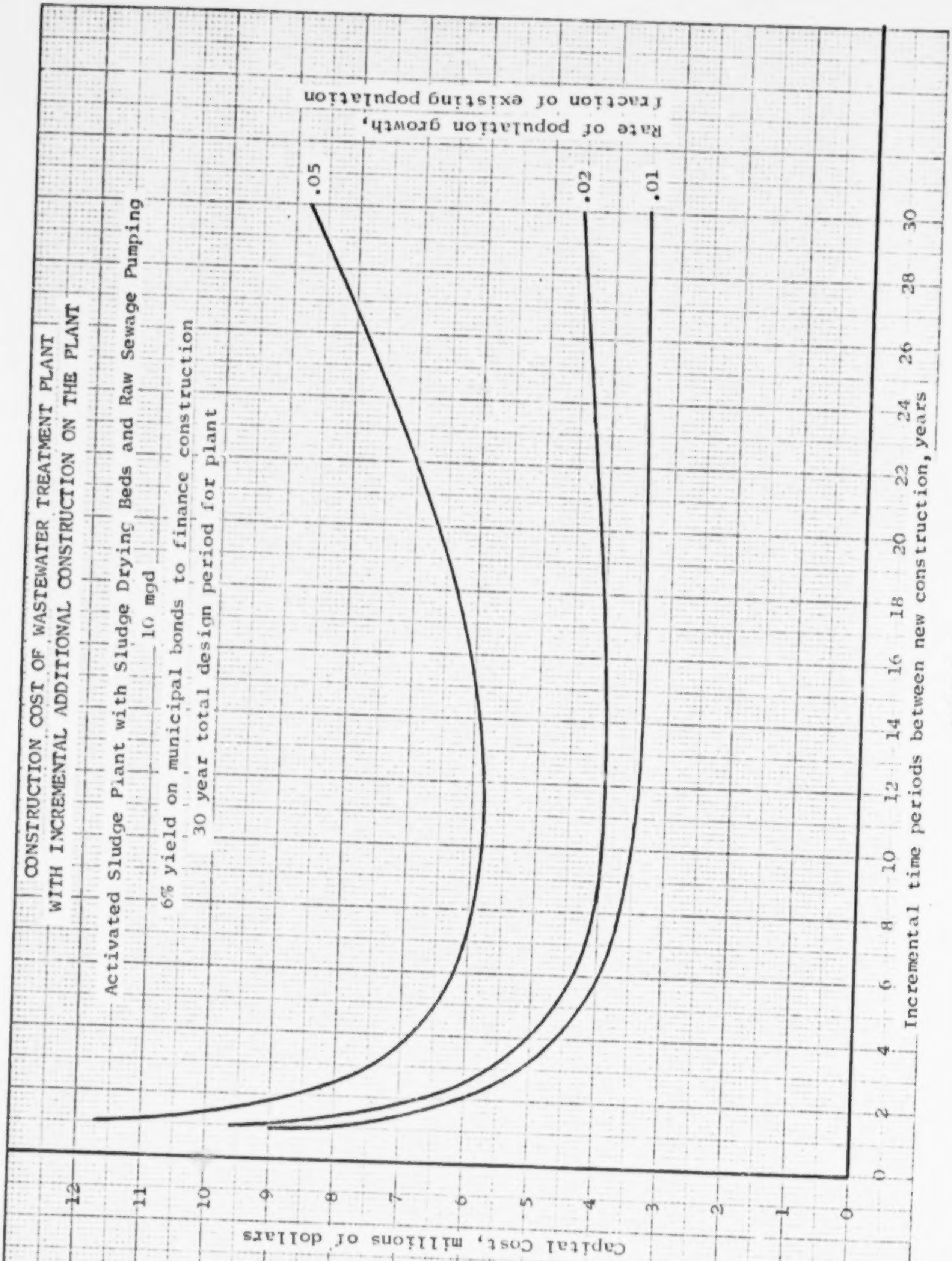


FIGURE 3

K&E 10 X 10 TO ½ INCH 46 1320
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.



CONSTRUCTION COST OF WASTEWATER TREATMENT PLANT
WITH INCREMENTAL ADDITIONAL CONSTRUCTION ON THE PLANT

Activated Sludge Plant with Sludge Drying Beds and Raw Sewage Pumping
10 mgd
6% yield on municipal bonds to finance construction
30 year total design period for plant

FIGURE 4

K&E 10 X 10 TO ½ INCH 46 1320
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

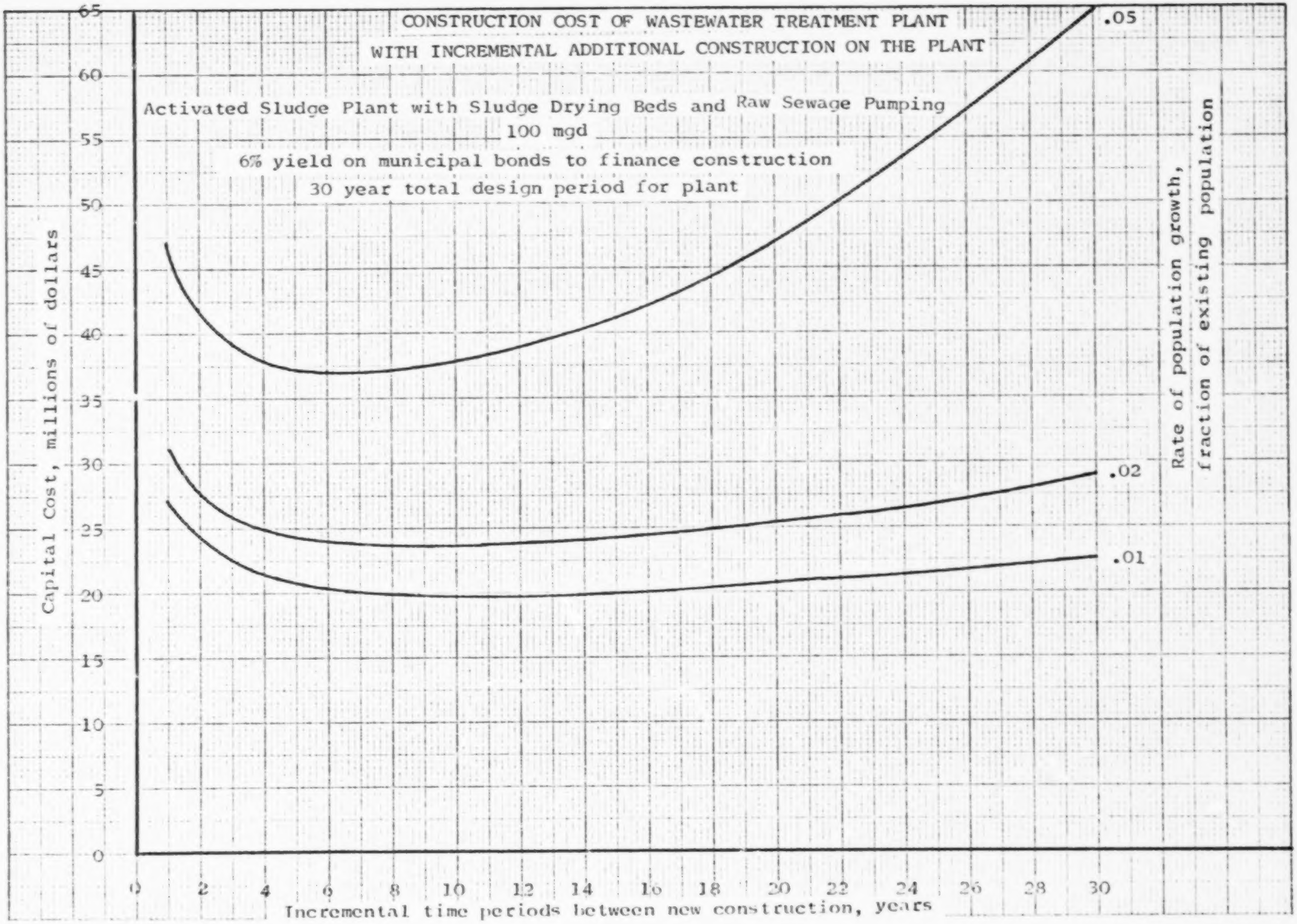


FIGURE 5

```
                                   TABLE 1

     RI            POPI            TT              TI              RPG        N
   CCOST           SCOST          FCOST


       0.040     10000.000        30.000          1.000           0.010      30
  12420433.3     3131615.2     9288818.1

       0.040     10000.000        30.000          2.000           0.010      15
   5916701.4     1435614.2     4481087.2

       0.040     10000.000        30.000          3.000           0.010      10
   3969982.3      923766.9     3046215.3

       0.040     10000.000        30.000          5.000           0.010       6
   2525676.1      539330.8     1986345.2

       0.040     10000.000        30.000          6.000           0.010       5
   2184270.7      446792.4     1737478.2

       0.040     10000.000        30.000         10.000           0.010       3
   1531598.5      263157.5     1268441.0

       0.040     10000.000        30.000         15.000           0.010       2
   1225289.6      164602.8     1060686.8

       0.040     10000.000        30.000         30.000           0.010       1
    949863.5           0.0      949863.5

       0.040     10000.000        30.000          1.000           0.020      30
  11249815.7     2803489.7     8446326.0

       0.040     10000.000        30.000          2.000           0.020      15
   5593388.3     1344564.6     4248823.6

       0.040     10000.000        30.000          3.000           0.020      10
   3863140.3      893688.8     2969451.5

       0.040     10000.000        30.000          5.000           0.020       6
   2552021.2      547110.5     2004910.7

       0.040     10000.000        30.000          6.000           0.020       5
   2236195.0      461834.4     1774360.5

       0.040     10000.000        30.000         10.000           0.020       3
   1622606.7      288355.7     1334251.0

       0.040     10000.000        30.000         15.000           0.020       2
   1330222.8      190179.6     1140043.2

       0.040     10000.000        30.000         30.000           0.020       1
   1079421.6           0.0     1079421.6

       0.040     10000.000        30.000          1.000           0.050      30
  10673853.1     2712873.0     7960980.1

       0.040     10000.000        30.000          2.000           0.050      15
   5797032.5     1462112.5     4334919.9

       0.040     10000.000        30.000          3.000           0.050      10
   4233398.7   1052437.2   3180961.4

       0.040   10000.000      30.000       5.000         0.050     6
   3003799.5    721880.4   2281919.0

       0.040   10000.000      30.000       6.000         0.050     5
   2699998.5    637108.9   2062889.5

       0.040   10000.000      30.000      10.000         0.050     3
   2105327.5    455864.8   1649462.7

       0.040   10000.000      30.000      15.000         0.050     2
   1834657.6    338842.1   1495815.4

       0.040   10000.000      30.000      30.000         0.050     1
   1721682.4         0.0   1721682.4

       0.040  100000.000      30.000       1.000         0.010    30
  12645306.9   2679611.3   9965695.6

       0.040  100000.000      30.000       2.000         0.010    15
   7849354.2   1425735.7   6423618.5

       0.040  100000.000      30.000       3.000         0.010    10
   6289763.2   1016247.4   5273515.8

       0.040  100000.000      30.000       5.000         0.010     6
   5043270.2    685957.4   4357312.8

       0.040  100000.000      30.000       6.000         0.010     5
   4729365.5    601118.5   4128247.0

       0.040  100000.000      30.000      10.000         0.010     3
   4096669.2    419710.1   3676959.1

       0.040  100000.000      30.000      15.000         0.010     2
   3782477.3    303977.3   3478500.0

       0.040  100000.000      30.000      30.000         0.010     1
   3528703.2         0.0   3528703.2

       0.040  100000.000      30.000       1.000         0.020    30
  13366037.2   2925376.5  10440660.7

       0.040  100000.000      30.000       2.000         0.020    15
   8689763.3   1699087.0   6990676.2

       0.040  100000.000      30.000       3.000         0.020    10
   7115069.4   1282976.2   5832093.2

       0.040  100000.000      30.000       5.000         0.020     6
   5827686.4    937153.1   4890533.2

       0.040  100000.000      30.000       6.000         0.020     5
   5498520.3    845491.6   4653028.6

       0.040  100000.000      30.000      10.000         0.020     3
   4831382.9    639858.6   4191524.3
```

```
     0.040  100000.000      30.000      15.000       0.020     2
 4514501.0    492898.9   4021602.1

     0.040  100000.000      30.000      30.000       0.020     1
 4389671.3         0.0   4389671.3

     0.040  100000.000      30.000       1.000       0.050    30
17472956.6   4529341.3  12943615.2

     0.040  100000.000      30.000       2.000       0.050    15
12467142.2   3153207.0   9313935.2

     0.040  100000.000      30.000       3.000       0.050    10
10679614.1   2646023.2   8033590.9

     0.040  100000.000      30.000       5.000       0.050     6
 9165719.4   2194189.8   6971529.6

     0.040  100000.000      30.000       6.000       0.050     5
 8778663.7   2067421.3   6711242.3

     0.040  100000.000      30.000      10.000       0.050     3
 8058070.4   1759610.7   6298459.7

     0.040  100000.000      30.000      15.000       0.050     2
 7878379.5   1483367.0   6395012.4

     0.040  100000.000      30.000      30.000       0.050     1
 8858575.0         0.0   8858575.0

     0.040 1000000.000      30.000       1.000       0.010    30
32616161.5   4252184.3  28363977.1

     0.040 1000000.000      30.000       2.000       0.010    15
27480536.7   2902558.1  24577978.5

     0.040 1000000.000      30.000       3.000       0.010    10
25596889.4   2405016.4  23191872.9

     0.040 1000000.000      30.000       5.000       0.010     6
23948348.1   1958095.3  21990252.7

     0.040 1000000.000      30.000       6.000       0.010     5
23508624.7   1831142.3  21677482.4

     0.040 1000000.000      30.000      10.000       0.010     3
22616007.8   1519555.5  21096452.2

     0.040 1000000.000      30.000      15.000       0.010     2
22246026.1   1247507.6  20998518.5

     0.040 1000000.000      30.000      30.000       0.010     1
22496457.3         0.0  22496457.3

     0.040 1000000.000      30.000       1.000       0.020    30
39439406.7   6424051.4  33015355.3

     0.040 1000000.000      30.000       2.000       0.020    15
33488336.6   4816722.7  28671613.8
```

```
      0.040 1000000.000      30.000     3.000     0.020    10
 31225045.9   4194318.0  27030727.8

      0.040 1000000.000      30.000     5.000     0.020     6
 29240862.9   3616857.8  25624005.0

      0.040 1000000.000      30.000     6.000     0.020     5
 28726985.8   3448054.0  25278931.8

      0.040 1000000.000      30.000    10.000     0.020     3
 27791433.3   3010538.4  24780894.9

      0.040 1000000.000      30.000    15.000     0.020     2
 27630011.7   2566777.1  25063234.5

      0.040 1000000.000      30.000    30.000     0.020     1
 29251345.5         0.0  29251345.5

      0.040 1000000.000      30.000     1.000     0.050    30
 67385456.6  17173564.1  50211892.5

      0.040 1000000.000      30.000     2.000     0.050    15
 58870555.4  14608986.9  44261568.5

      0.040 1000000.000      30.000     3.000     0.050    10
 55615319.3  13575865.7  42039453.6

      0.040 1000000.000      30.000     5.000     0.050     6
 52988550.4  12599850.1  40388700.3

      0.040 1000000.000      30.000     6.000     0.050     5
 52442086.8  12306127.8  40135959.0

      0.040 1000000.000      30.000    10.000     0.050     3
 52186185.5  11444899.6  40741285.8

      0.040 1000000.000      30.000    15.000     0.050     2
 53830139.8  10221947.7  43608192.0

      0.040 1000000.000      30.000    30.000     0.050     1
 65017643.5         0.0  65017643.5

      0.000       0.000       0.000     0.000     0.000     0
        0.0         0.0         0.0
```

TABLE 2

RI	POPI	TT	TI	RPG	N
CCOST	SCOST	FCOST			
0.050	10000.000	30.000	1.000	0.010	30
11175035.0	2372714.8	8802320.1			
0.050	10000.000	30.000	2.000	0.010	15
5361380.1	1098173.2	4263206.8			
0.050	10000.000	30.000	3.000	0.010	10
3622395.0	713430.2	2908964.8			
0.050	10000.000	30.000	5.000	0.010	6
2333693.1	424576.8	1909116.2			
0.050	10000.000	30.000	6.000	0.010	5
2029606.0	355109.8	1674496.1			
0.050	10000.000	30.000	10.000	0.010	3
1450245.0	217318.4	1232926.5			
0.050	10000.000	30.000	15.000	0.010	2
1181269.7	142592.8	1038676.8			
0.050	10000.000	30.000	30.000	0.010	1
949863.5	0.0	949863.5			
0.050	10000.000	30.000	1.000	0.020	30
10133769.6	2124105.7	8009663.9			
0.050	10000.000	30.000	2.000	0.020	15
5073648.5	1028524.9	4045123.6			
0.050	10000.000	30.000	3.000	0.020	10
3527453.2	690200.7	2837252.5			
0.050	10000.000	30.000	5.000	0.020	6
2357824.7	430701.1	1927123.5			
0.050	10000.000	30.000	6.000	0.020	5
2076820.8	367065.2	1709755.6			
0.050	10000.000	30.000	10.000	0.020	3
1533712.8	238127.4	1295585.3			
0.050	10000.000	30.000	15.000	0.020	2
1279362.9	164749.6	1114613.2			
0.050	10000.000	30.000	30.000	0.020	1
1079421.6	0.0	1079421.6			
0.050	10000.000	30.000	1.000	0.050	30
9603632.9	2055448.6	7548184.3			
0.050	10000.000	30.000	2.000	0.050	15
5240693.4	1118443.2	4122250.2			
0.050	10000.000	30.000	3.000	0.050	10

```
   3845658.7     812803.0   3032855.6

       0.050    10000.000      30.000        5.000        0.050      6
   2753231.4     568285.1   2184946.3

       0.050    10000.000      30.000        6.000        0.050      5
   2485036.5     506373.1   1978663.3

       0.050    10000.000      30.000       10.000        0.050      3
   1967181.0     376458.3   1590722.7

       0.050    10000.000      30.000       15.000        0.050      2
   1744040.7     293533.7   1450507.0

       0.050    10000.000      30.000       30.000        0.050      1
   1721682.4          0.0   1721682.4

       0.050   100000.000      30.000        1.000        0.010     30
  11584248.8    2030247.3   9554001.4

       0.050   100000.000      30.000        2.000        0.010     15
   7300678.3    1090616.7   6210061.6

       0.050   100000.000      30.000        3.000        0.010     10
   5909452.8     784853.4   5124599.4

       0.050   100000.000      30.000        5.000        0.010      6
   4800412.3     540005.4   4260406.8

       0.050   100000.000      30.000        6.000        0.010      5
   4522360.0     477768.0   4044592.0

       0.050   100000.000      30.000       10.000        0.010      3
   3967376.7     346601.3   3620775.4

       0.050   100000.000      30.000       15.000        0.010      2
   3701184.4     263330.8   3437853.5

       0.050   100000.000      30.000       30.000        0.010      1
   3528703.2          0.0   3528703.2

       0.050   100000.000      30.000        1.000        0.020     30
  12214494.8    2216455.0   9998039.8

       0.050   100000.000      30.000        2.000        0.020     15
   8041301.6    1299716.8   6741584.7

       0.050   100000.000      30.000        3.000        0.020     10
   6639482.9     990849.4   5648633.5

       0.050   100000.000      30.000        5.000        0.020      6
   5499242.2     737753.9   4761488.2

       0.050   100000.000      30.000        6.000        0.020      5
   5210222.6     671995.3   4538227.2

       0.050   100000.000      30.000       10.000        0.020      3
   4635607.1     528402.4   4107204.7
```

```
      0.050  100000.000       30.000      15.000        0.020     2
  4382684.7    426990.7    3955693.9

      0.050  100000.000       30.000      30.000        0.020     1
  4389671.3         0.0    4389671.3

      0.050  100000.000       30.000       1.000        0.050    30
 15752605.9   3431722.8   12320883.0

      0.050  100000.000       30.000       2.000        0.050    15
 11312309.3   2412046.0    8900263.2

      0.050  100000.000       30.000       3.000        0.050    10
  9739266.3   2043538.0    7695728.2

      0.050  100000.000       30.000       5.000        0.050     6
  8426753.3   1727329.5    6699423.8

      0.050  100000.000       30.000       6.000        0.050     5
  8099742.8   1643183.1    6456559.7

      0.050  100000.000       30.000      10.000        0.050     3
  7532659.2   1453106.3    6079552.9

      0.050  100000.000       30.000      15.000        0.050     2
  7481681.4   1285018.0    6196663.4

      0.050  100000.000       30.000      30.000        0.050     1
  8858575.0         0.0    8858575.0

      0.050 1000000.000       30.000       1.000        0.010    30
 30945385.2   3221730.7   27723654.4

      0.050 1000000.000       30.000       2.000        0.010    15
 26372354.9   2220312.2   24152042.7

      0.050 1000000.000       30.000       3.000        0.010    10
 24703648.1   1857407.2   22846240.9

      0.050 1000000.000       30.000       5.000        0.010     6
 23259559.4   1541469.1   21718090.2

      0.050 1000000.000       30.000       6.000        0.010     5
 22881705.9   1455388.8   21426317.0

      0.050 1000000.000       30.000      10.000        0.010     3
 22149424.4   1254866.1   20894558.3

      0.050 1000000.000       30.000      15.000        0.010     2
 21912404.2   1080696.7   20831707.5

      0.050 1000000.000       30.000      30.000        0.010     1
 22496457.3         0.0   22496457.3

      0.050 1000000.000       30.000       1.000        0.020    30
 36951988.1   4867278.1   32084709.9

      0.050 1000000.000       30.000       2.000        0.020    15
 31677861.3   3684552.6   27993308.6
```

```
        0.050 1000000.000        30.000          3.000           0.020      10
   29691398.3   3239294.5    26452103.7

        0.050 1000000.000        30.000          5.000           0.020       6
   27986915.0   2847294.8    25139620.2

        0.050 1000000.000        30.000          6.000           0.020       5
   27562483.8   2740507.7    24821976.1

        0.050 1000000.000        30.000         10.000           0.020       3
   26875053.9   2486136.5    24388917.3

        0.050 1000000.000        30.000         15.000           0.020       2
   26943576.4   2223559.5    24720016.9

        0.050 1000000.000        30.000         30.000           0.020       1
   29251345.5         0.0    29251345.5

        0.050 1000000.000        30.000          1.000           0.050      30
   61074129.0  13011806.4    48062322.6

        0.050 1000000.000        30.000          2.000           0.050      15
   53659456.7  11175146.3    42484310.3

        0.050 1000000.000        30.000          3.000           0.050      10
   50897003.8  10484714.6    40412289.2

        0.050 1000000.000        30.000          5.000           0.050       6
   48815001.0   9918965.5    38896035.5

        0.050 1000000.000        30.000          6.000           0.050       5
   48458491.0   9780890.1    38677600.8

        0.050 1000000.000        30.000         10.000           0.050       3
   48793058.6   9451327.0    39341731.6

        0.050 1000000.000        30.000         15.000           0.050       2
   51096476.3   8855116.0    42241360.3

        0.050 1000000.000        30.000         30.000           0.050       1
   65017643.5         0.0    65017643.5

        0.000       0.000         0.000          0.000           0.000       0
          0.0         0.0           0.0
```

TABLE 3

RI CCOST	POPI SCOST	TT FCOST	TI	RPG	N
0.060 10126351.1	10000.000 1802457.9	30.000 8323893.2	1.000	0.010	30
0.060 4892879.6	10000.000 842184.0	30.000 4050695.5	2.000	0.010	15
0.060 3328603.5	10000.000 552337.1	30.000 2776266.3	3.000	0.010	10
0.060 2170852.9	10000.000 334997.9	30.000 1835854.9	5.000	0.010	6
0.060 1898205.6	10000.000 282855.8	30.000 1615349.7	6.000	0.010	5
0.060 1380739.6	10000.000 179789.8	30.000 1200949.7	10.000	0.010	3
0.060 1143472.3	10000.000 123694.2	30.000 1019778.1	15.000	0.010	2
0.060 949863.5	10000.000 0.0	30.000 949863.5	30.000	0.010	1
0.060 9193777.0	10000.000 1613599.3	30.000 7580177.7	1.000	0.020	30
0.060 4635232.6	10000.000 788771.0	30.000 3846461.5	2.000	0.020	15
0.060 3243830.6	10000.000 534352.8	30.000 2709477.7	3.000	0.020	10
0.060 2193214.0	10000.000 339830.1	30.000 1853383.9	5.000	0.020	6
0.060 1941515.5	10000.000 292378.6	30.000 1649136.8	6.000	0.020	5
0.060 1457813.7	10000.000 197005.4	30.000 1260808.3	10.000	0.020	3
0.060 1235692.4	10000.000 142914.4	30.000 1092778.0	15.000	0.020	2
~~0.060~~ 1079421.6	~~10000.000~~ 0.0	~~30.000~~ 1079421.6	~~30.000~~	~~0.020~~	~~1~~
0.060 8704038.7	10000.000 1561443.2	30.000 7142595.5	1.000	0.050	30
0.060 4773069.0	10000.000 857728.9	30.000 3915340.0	2.000	0.050	15
0.060	10000.000	30.000	3.000	0.050	10

```
  3519493.4     629271.4    2890221.9

      0.060    10000.000       30.000         5.000          0.050      6
  2541921.6     448386.1    2093535.5

      0.060    10000.000       30.000         6.000          0.050      5
  2303479.7     403341.6    1900138.0

      0.060    10000.000       30.000        10.000          0.050      3
  1849695.4     311448.0    1538247.3

      0.060    10000.000       30.000        15.000          0.050      2
  1666233.2     254630.0    1411603.2

      0.060    10000.000       30.000        30.000          0.050      1
  1721682.4          0.0    1721682.4

      0.060   100000.000       30.000         1.000          0.010     30
 10691673.8    1542298.8    9149374.9

      0.060   100000.000       30.000         2.000          0.010     15
  6838331.2     836388.9    6001942.3

      0.060   100000.000       30.000         3.000          0.010     10
  5588405.1     607632.8    4980772.2

      0.060   100000.000       30.000         5.000          0.010      6
  4594676.5     426073.0    4168603.5

      0.060   100000.000       30.000         6.000          0.010      5
  4346702.4     380556.8    3966145.6

      0.060   100000.000       30.000        10.000          0.010      3
  3857003.5     286747.0    3570256.5

      0.060   100000.000       30.000        15.000          0.010      2
  3631382.8     228430.0    3402952.7

      0.060   100000.000       30.000        30.000          0.010      1
  3528703.2          0.0    3528703.2

      0.060   100000.000       30.000         1.000          0.020     30
 11247112.6    1683753.4    9563359.2

      0.060   100000.000       30.000         2.000          0.020     15
  7495910.8     996746.9    6499163.9

      0.060   100000.000       30.000         3.000          0.020     10
  6238883.0     767114.8    5471768.2

      0.060   100000.000       30.000         5.000          0.020      6
  5221652.2     582099.7    4639552.4

      0.060   100000.000       30.000         6.000          0.020      5
  4966139.9     535264.8    4430875.0

      0.060   100000.000       30.000        10.000          0.020      3
  4468739.6     437153.0    4031586.5
```

```
     0.060   100000.000       30.000       15.000       0.020    2
 4269501.5     370399.1    3899102.3

     0.060   100000.000       30.000       30.000       0.020    1
 4389671.3          0.0    4389671.3

     0.060   100000.000       30.000        1.000       0.050   30
14319249.3    2606944.5   11712304.7

     0.060   100000.000       30.000        2.000       0.050   15
10350314.5    1849787.1    8500527.4

     0.060   100000.000       30.000        3.000       0.050   10
 8954957.6    1582105.5    7372852.0

     0.060   100000.000       30.000        5.000       0.050    6
 7808010.9    1362890.7    6445120.1

     0.060   100000.000       30.000        6.000       0.050    5
 7529996.0    1308845.4    6221150.5

     0.060   100000.000       30.000       10.000       0.050    3
 7087381.7    1202170.5    5885211.2

     0.060   100000.000       30.000       15.000       0.050    2
 7141059.4    1114707.0    6026352.3

     0.060   100000.000       30.000       30.000       0.050    1
 8858575.0          0.0    8858575.0

     0.060  1000000.000       30.000        1.000       0.010   30
29542420.5    2447421.8   27094998.6

     0.060  1000000.000       30.000        2.000       0.010   15
25440249.3    1702747.3   23737502.0

     0.060  1000000.000       30.000        3.000       0.010   10
23950919.3    1438003.1   22512916.2

     0.060  1000000.000       30.000        5.000       0.010    6
22676926.3    1216243.9   21460682.3

     0.060  1000000.000       30.000        6.000       0.010    5
22350440.9    1159261.6   21191179.2

     0.060  1000000.000       30.000       10.000       0.010    3
21751412.3    1038164.2   20713248.1

     0.060  1000000.000       30.000       15.000       0.010    2
21625942.0     937465.6   20688476.4

     0.060  1000000.000       30.000       30.000       0.010    1
22496457.3          0.0   22496457.3

     0.060  1000000.000       30.000        1.000       0.020   30
34870376.0    3697479.2   31172896.8

     0.060  1000000.000       30.000        2.000       0.020   15
30160575.7    2825666.6   27334909.1
```

```
      0.060 1000000.000     30.000      3.000      0.020   10
 28403695.4   2507859.2 25895836.2

      0.060 1000000.000     30.000      5.000      0.020    6
 26929799.7   2246561.3 24683238.3

      0.060 1000000.000     30.000      6.000      0.020    5
 26578781.2   2182897.9 24395883.2

      0.060 1000000.000     30.000     10.000      0.020    3
 26094920.5   2056807.5 24038113.0

      0.060 1000000.000     30.000     15.000      0.020    2
 26354173.5   1928858.0 24425315.4

      0.060 1000000.000     30.000     30.000      0.020    1
 29251345.5         0.0 29251345.5

      0.060 1000000.000     30.000      1.000      0.050   30
 55857312.5   9884556.2 45972756.2

      0.060 1000000.000     30.000      2.000      0.050   15
 49346171.2   8570168.6 40776002.5

      0.060 1000000.000     30.000      3.000      0.050   10
 46982830.4   8117257.6 38865572.8

      0.060 1000000.000     30.000      5.000      0.050    6
 45334467.2   7826223.1 37508244.1

      0.060 1000000.000     30.000      6.000      0.050    5
 45127057.1   7790777.3 37336279.7

      0.060 1000000.000     30.000     10.000      0.050    3
 45922328.5   7819184.6 38103143.9

      0.060 1000000.000     30.000     15.000      0.050    2
 48749234.7   7681495.2 41067739.5

      0.060 1000000.000     30.000     30.000      0.050    1
 65017643.5         0.0 65017643.5

      0.000       0.000      0.000      0.000      0.000    0
        0.0         0.0        0.0
```

TABLE 4

```
PAGE   2                    PRESENT WORTH OF FUNDS TO FINANCE PLANT CONSTRUCTION

      IN=2
      IO=5
      READ(IN,5) NCASE
    5 FORMAT(I2)
      WRITE(IO,15)
   15 FORMAT(1H1,15X,'RI',9X,'POPI',9X,'TT',10X,'TI',10X,'RPG',7X,'N',
     . /,14X,'CCOST',7X,'SCOST',7X,'FCOST',//)
      DO 200 II=1,NCASE
      READ(IN,10) RI,POPI,TT,TI,RPG
   10 FORMAT(8F10.0)
      TMGD=0.
      TC=0.
      CCOST=0.
      SCOST=0.
      N=TT/TI
      WRITE(IO,20) RI,POPI,TT,TI,RPG,N
   20 FORMAT(10X,5F12.3,I6)
      DO 100 I=1,N
      TC=TC+TI
      POP=POPI*EXP(RPG*TC)
      XMGD=POP/10000.
      X=ALOG(XMGD-TMGD)
      CAP=EXP(-.16411+.34939*X+.088743*X**2.-.0048429*X**3.)
      CAP=CAP*1000000.
      SURP=(TC-TI)/TT*CAP
      CCOST=CCOST+CAP/(1.+RI)**(TC-TI)
      SCOST=SCOST+SURP
      TMGD=XMGD
  100 CONTINUE
      SCOST=SCOST/(1.+RI)**(TC-TI)
      FCOST=CCOST-SCOST
      WRITE(IO,30) CCOST,SCOST,FCOST
   30 FORMAT(10X,3F12.1,/)
  200 CONTINUE
      CALL EXIT
      END
VARIABLE ALLOCATIONS
    RI(R )=0000        POPI(R )=0003          TT(R )=0006          TI(R )=0009
    TC(R )=0012       CCOST(R )=0015       SCOST(R )=0018         POP(R )=001B
   CAP(R )=0024        SURP(R )=0027       FCOST(R )=002A          IN(I )=003C
    II(I )=003F           N(I )=0040           I(I )=0041

STATEMENT ALLOCATIONS
 5    =0063  15   =0065  10   =008E  20   =0091  30   =0096  100  =017E  200  =01

FEATURES SUPPORTED
 ONE WORD INTEGERS
 EXTENDED PRECISION
 IOCS

CALLED SUBPROGRAMS
 EEXP     EALOG    EAXB     ESUB     EMPY     EDIV     ELD      ESTO     ESBR     EDVR
 SFIO     SIOF     SIOI     PRNZ     SNR      SDFIO

REAL CONSTANTS
  .000000000E 00=0042    .100000000E 05=0045    .164110000E 00=0048    .3493
  .200000000E 01=0051    .484290000E-02=0054    .300000000E 01=0057    .100
```

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

Ohio Basin Region
4676 Columbia Parkway
Cincinnati, Ohio 45226

TO : Dr. William N. Fitch
Systems and Economics Branch

DATE: April 28, 1971

THRU : F. M. Middleton, Director of Research, AWTRL FMM

FROM : Robert Smith and Richard G. Eilers
Treatment Optimization Research Program

SUBJECT: The Economic Advantages Associated with Staged Construction of Interceptor Sewers

Using the computer program given in TABLE I, the potential economic advantages of staged construction of interceptor sewers were computed. The interceptor sewers used in this example were assumed to have a slope of .001 ft/ft. A cost relationship was developed for average volume flow transmitted in mgd (X) versus total pipeline cost in cents/1000 gallons/mile (Y). This relationship is given in FIGURE 1, and was developed using another computer program which computes the economics of consolidating sewage treatment plants by means of interceptor sewers and force mains. The mathematical relationship for the .001 slope line is:

```
Y = EXP(.84343 - .502285 * ALOG(X))
```

Assuming that Y is the amortization cost per mile of pipeline, the capital cost per mile of pipeline (CAP) can be computed with the following relationship:

```
CAP = Y * X * 3650./AF
```

where AF is the amortization factor given by:

```
AF = RI * (1. + RI) **TT/((1. + RI) **TT - 1.)
```

where RI is the fractional yield on municipal bonds to finance the pipeline, and TT is the total pipeline design period in years.

The initial population was taken to be 10,000 (1 mgd), 100,000 (10 mgd), 1,000,000 (100 mgd) based on 100 gallons/day/person. The population growth rate was assumed to be exponential and is given by the following relationship:

```
POP = POPI * EXP(RPG * TC)
```

The time increment (TI) for building stages was always taken as a multiple of 30 years. The incremental pipeline was sized to just meet the requirements of the growing population at the end of the time increment (TI). Each incremental pipeline was assumed to

Buy U.S. Savings Bonds Regularly on the Payroll Savings Plan

depreciate in a straight line over the 30 year period. For incremental pipelines built after the start of the 30 year period, a credit was assumed to occur at the end of the 30 year period.

All expenditures and credits were converted to a present worth by dividing by the factor (1. + RI) **T, where T is the time at which the expenditure or the credit occurred after the beginning of the 30 year period. All credits due to useful life remaining at the end of the 30 year period were taken at the end of the 30 year period.

TABLES 2, 3 and 4 show computed results for 1, 10 and 100 mgd pipelines based on a design period (TT) of 30 years. For interest yields (RI) of .04, .05 and .06, the rate of population growth (RPG) was varied as .01, .02 and .05 for time increments (TI) of 1, 2, 3, 5, 6, 10, 15 and 30 years.

Bob Smith
Robert Smith

Richard G. Eilers
Richard G. Eilers

Attachments

DEFINITIONS

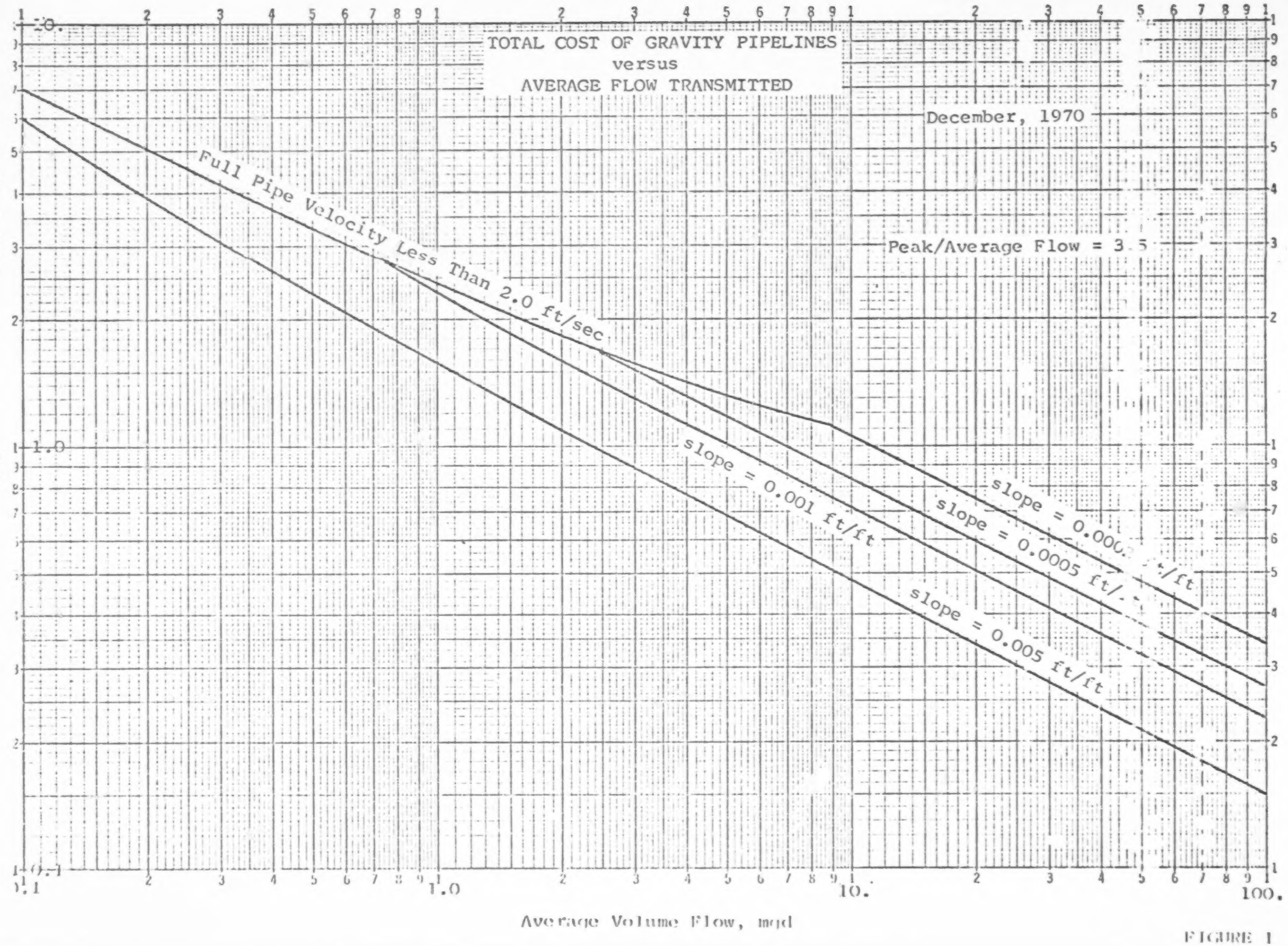
The following six parameters are input to the program:

RI	yield on municipal bonds to finance the pipeline, fraction
POPI	initial design population of the pipeline
TT	total pipeline design period, years
TI	time increment for addition of increased capacity to the pipeline, years
TC	cumulative time, years
RPG	rate of population growth, fraction of existing population

The following four parameters are computed and printed out by the program:

N	number of time increment additions to the pipeline
CCOST	total construction cost of original pipeline and pipeline additions, dollars/mile
SCOST	total salvage value of the pipeline additions at the end of the original design period of the pipeline, dollars/mile
FCOST	CCOST - SCOST

CCOST, SCOST and FCOST are expressed as present worth dollars at the time beginning the design period of the original pipeline.



TOTAL COST OF GRAVITY PIPELINES
versus
AVERAGE FLOW TRANSMITTED

FIGURE 1

TABLE I

```
PAGE   2                    PRESENT WORTH OF FUNDS TO FINANCE PLANT CONSTRUCTION

      IN=2
      IO=5
      READ(IN,5) NCASE
    5 FORMAT(I2)
      WRITE(IO,15)
   15 FORMAT(1H1,15X,'RI',9X,'POPI',9X,'TT',10X,'TI',10X,'RPG',7X,'N',
     . /,14X,'CCOST',7X,'SCOST',7X,'FCOST',//)
      AF=.06*(1.+.06)**50./((1.+.06)**50.-1.)
      DO 200 II=1,NCASE
      READ(IN,10) RI,POPI,TT,TI,RPG
   10 FORMAT(8F10.0)
      TMGD=0.
      TC=0.
      CCOST=0.
      SCOST=0.
      N=TT/TI
      WRITE(IO,20) RI,POPI,TT,TI,RPG,N
   20 FORMAT(10X,5F12.3,I6)
      DO 100 I=1,N
      TC=TC+TI
      POP=POPI*EXP(RPG*TC)
      XMGD=POP/10000.
      X=ALOG(XMGD-TMGD)
      CAP=EXP(.84343-.502285*X)
      X=EXP(X)
      CAP=CAP*X*3650./AF
      SURP=(TC-TI)/TT*CAP
      CCOST=CCOST+CAP/(1.+RI)**(TC-TI)
      SCOST=SCOST+SURP
      TMGD=XMGD
  100 CONTINUE
      SCOST=SCOST/(1.+RI)**(TC-TI)
      FCOST=CCOST-SCOST
      WRITE(IO,30) CCOST,SCOST,FCOST
   30 FORMAT(10X,3F12.1,/)
  200 CONTINUE
      CALL EXIT
      END
```

TABLE 2

```
       RI           POPI           TT            TI             RPG        N
    CCOST          SCOST          FCOST


       0.040     10000.000        30.000         1.000          0.010     30
    379209.2       69505.3     309703.8

       0.040     10000.000        30.000         2.000          0.010     15
    301873.4       49312.9     252560.5

       0.040     10000.000        30.000         3.000          0.010     10
    266898.4       40374.3     226524.1

       0.040     10000.000        30.000         5.000          0.010      6
    230981.3       31334.6     199646.6

       0.040     10000.000        30.000         6.000          0.010      5
    219989.6       28570.1     191419.5

       0.040     10000.000        30.000        10.000          0.010      3
    193470.0       21620.1     171849.9

       0.040     10000.000        30.000        15.000          0.010      2
    176404.9       16159.6     160245.2

       0.040     10000.000        30.000        30.000          0.010      1
    155254.3           0.0     155254.3

       0.040     10000.000        30.000         1.000          0.020     30
    504414.8      108693.9     395720.8

       0.040     10000.000        30.000         2.000          0.020     15
    388905.8       77176.5     311729.3

       0.040     10000.000        30.000         3.000          0.020     10
    336965.9       63236.4     273729.4

       0.040     10000.000        30.000         5.000          0.020      6
    284077.6       49155.2     234922.4

       0.040     10000.000        30.000         6.000          0.020      5
    268054.7       44854.0     223200.6

       0.040     10000.000        30.000        10.000          0.020      3
    229996.3       34052.0     195944.3

       0.040     10000.000        30.000        15.000          0.020      2
    206367.4       25556.5     180810.9

       0.040     10000.000        30.000        30.000          0.020      1
    180256.2           0.0     180256.2

       0.040     10000.000        30.000         1.000          0.050     30
    855238.9      234584.8     620654.1

       0.040     10000.000        30.000         2.000          0.050     15
    636018.0      166917.9     469100.0

       0.040     10000.000        30.000         3.000          0.050     10
```

```
  538608.6    137063.6    401544.9

     0.040   10000.000      30.000       5.000        0.050     6
  441132.5    107013.2    334119.3

     0.040   10000.000      30.000       6.000        0.050     5
  412215.7     97869.0    314346.6

     0.040   10000.000      30.000      10.000        0.050     3
  345852.0     74992.7    270859.2

     0.040   10000.000      30.000      15.000        0.050     2
  308182.9     56977.0    251205.8

     0.040   10000.000      30.000      30.000        0.050     1
  282117.2         0.0    282117.2

     0.040  100000.000      30.000       1.000        0.010    30
 1192872.1    218641.8    974230.2

     0.040  100000.000      30.000       2.000        0.010    15
  949598.3    155122.9    794475.3

     0.040  100000.000      30.000       3.000        0.010    10
  839577.9    127004.8    712573.1

     0.040  100000.000      30.000       5.000        0.010     6
  726594.0     98568.7    628025.2

     0.040  100000.000      30.000       6.000        0.010     5
  692017.8     89872.5    602145.2

     0.040  100000.000      30.000      10.000        0.010     3
  608595.5     68010.0    540585.5

     0.040  100000.000      30.000      15.000        0.010     2
  554914.1     50833.2    504080.9

     0.040  100000.000      30.000      30.000        0.010     1
  488381.0         0.0    488381.0

     0.040  100000.000      30.000       1.000        0.020    30
 1586729.2    341916.8   1244812.3

     0.040  100000.000      30.000       2.000        0.020    15
 1223374.7    242772.8    980601.8

     0.040  100000.000      30.000       3.000        0.020    10
 1059988.0    198921.9    861066.0

     0.040  100000.000      30.000       5.000        0.020     6
  893618.4    154626.8    738991.6

     0.040  100000.000      30.000       6.000        0.020     5
  843215.2    141096.6    702118.5

     0.040  100000.000      30.000      10.000        0.020     3
  723495.7    107116.8    616378.8
```

```
     0.040  100000.000      30.000        15.000         0.020     2
  649166.7     80392.8    568773.8

     0.040  100000.000      30.000        30.000         0.020     1
  567028.9         0.0    567028.9

     0.040  100000.000      30.000         1.000         0.050    30
 2690311.0    737929.6   1952381.4

     0.040  100000.000      30.000         2.000         0.050    15
 2000711.3    525071.0   1475640.3

     0.040  100000.000      30.000         3.000         0.050    10
 1694292.1    431158.9   1263133.1

     0.040  100000.000      30.000         5.000         0.050     6
 1387663.3    336629.7   1051033.6

     0.040  100000.000      30.000         6.000         0.050     5
 1296700.2    307865.1    988835.1

     0.040  100000.000      30.000        10.000         0.050     3
 1087940.9    235903.4    852037.5

     0.040  100000.000      30.000        15.000         0.050     2
  969445.8    179231.8    790213.9

     0.040  100000.000      30.000        30.000         0.050     1
  887451.5         0.0    887451.5

     0.040 1000000.000      30.000         1.000         0.010    30
 3752398.0    687778.0   3064620.0

     0.040 1000000.000      30.000         2.000         0.010    15
 2987135.7    487967.7   2499167.9

     0.040 1000000.000      30.000         3.000         0.010    10
 2641046.4    399516.8   2241529.5

     0.040 1000000.000      30.000         5.000         0.010     6
 2285634.7    310066.1   1975568.5

     0.040 1000000.000      30.000         6.000         0.010     5
 2176869.0    282710.6   1894158.4

     0.040 1000000.000      30.000        10.000         0.010     3
 1914448.8    213938.0   1700510.8

     0.040 1000000.000      30.000        15.000         0.010     2
 1745584.3    159905.3   1585678.9

     0.040 1000000.000      30.000        30.000         0.010     1
 1536292.1         0.0   1536292.1

     0.040 1000000.000      30.000         1.000         0.020    30
 4991347.7   1075562.2   3915785.5

     0.040 1000000.000      30.000         2.000         0.020    15
 3848349.4    763686.5   3084662.8
```

```
     0.040 1000000.000      30.000        3.000        0.020   10
 3334386.7    625745.5   2708641.1

     0.040 1000000.000      30.000        5.000        0.020    6
 2811040.6    486407.0   2324633.5

     0.040 1000000.000      30.000        6.000        0.020    5
 2652488.1    443845.4   2208642.6

     0.040 1000000.000      30.000       10.000        0.020    3
 2275888.3    336955.6   1938932.7

     0.040 1000000.000      30.000       15.000        0.020    2
 2042072.9    252890.3   1789182.5

     0.040 1000000.000      30.000       30.000        0.020    1
 1783693.6         0.0   1783693.6

     0.040 1000000.000      30.000        1.000        0.050   30
 8462866.6   2321292.9   6141573.6

     0.040 1000000.000      30.000        2.000        0.050   15
 6293604.4   1651707.1   4641897.2

     0.040 1000000.000      30.000        3.000        0.050   10
 5329706.5   1356289.5   3973416.9

     0.040 1000000.000      30.000        5.000        0.050    6
 4365149.4   1058930.5   3306218.8

     0.040 1000000.000      30.000        6.000        0.050    5
 4079008.3    968446.1   3110562.2

     0.040 1000000.000      30.000       10.000        0.050    3
 3422317.7    742077.4   2680240.2

     0.040 1000000.000      30.000       15.000        0.050    2
 3049569.6    563806.6   2485762.9

     0.040 1000000.000      30.000       30.000        0.050    1
 2791641.5         0.0   2791641.5

     0.000       0.000       0.000        0.000        0.000    0
       0.0         0.0         0.0
```

TABLE 3

```
      RI           POPI            TT             TI             RPG         N
   CCOST          SCOST          FCOST


     0.050     10000.000        30.000         1.000          0.010       30
  351970.8       52661.7      299309.1

     0.050     10000.000        30.000         2.000          0.010       15
  283047.8       37721.9      245325.9

     0.050     10000.000        30.000         3.000          0.010       10
  251886.2       31181.3      220704.9

     0.050     10000.000        30.000         5.000          0.010        6
  219934.3       24667.5      195266.8

     0.050     10000.000        30.000         6.000          0.010        5
  210184.4       22707.4      187476.9

     0.050     10000.000        30.000        10.000          0.010        3
  186817.6       17854.1      168963.5

     0.050     10000.000        30.000        15.000          0.010        2
  172083.3       13998.8      158084.4

     0.050     10000.000        30.000        30.000          0.010        1
  155254.3           0.0      155254.3

     0.050     10000.000        30.000         1.000          0.020       30
  462287.3       82353.6      379933.7

     0.050     10000.000        30.000         2.000          0.020       15
  359753.5       59036.1      300717.4

     0.050     10000.000        30.000         3.000          0.020       10
  313688.7       48837.8      264850.8

     0.050     10000.000        30.000         5.000          0.020        6
  266901.5       38696.4      228205.1

     0.050     10000.000        30.000         6.000          0.020        5
  252786.9       35649.9      217137.0

     0.050     10000.000        30.000        10.000          0.020        3
  219571.5       28120.5      191451.0

     0.050     10000.000        30.000        15.000          0.020        2
  199532.8       22139.2      177393.6

     0.050     10000.000        30.000        30.000          0.020        1
  180256.2           0.0      180256.2

     0.050     10000.000        30.000         1.000          0.050       30
  767186.8      177736.7      589450.1

     0.050     10000.000        30.000         2.000          0.050       15
  574874.5      127683.9      447190.5

     0.050     10000.000        30.000         3.000          0.050       10
  489609.3    105855.0    383754.3

     0.050   10000.000      30.000       5.000       0.050      6
  404692.6     84243.9    320448.7

     0.050   10000.000      30.000       6.000       0.050      5
  379689.1     77786.1    301902.9

     0.050   10000.000      30.000      10.000       0.050      3
  323229.2     61929.8    261299.3

     0.050   10000.000      30.000      15.000       0.050      2
  292945.4     49358.3    243587.1

     0.050   10000.000      30.000      30.000       0.050      1
  282117.2         0.0    282117.2

     0.050  100000.000      30.000       1.000       0.010     30
 1107188.9    165657.2    941531.7

     0.050  100000.000      30.000       2.000       0.010     15
  890378.9    118661.3    771717.6

     0.050  100000.000      30.000       3.000       0.010     10
  792354.4     98086.4    694267.9

     0.050  100000.000      30.000       5.000       0.010      6
  691843.9     77596.1    614247.7

     0.050  100000.000      30.000       6.000       0.010      5
  661173.8     71430.5    589743.2

     0.050  100000.000      30.000      10.000       0.010      3
  587669.2     56163.4    531505.7

     0.050  100000.000      30.000      15.000       0.010      2
  541319.8     44036.0    497283.7

     0.050  100000.000      30.000      30.000       0.010      1
  488381.0         0.0    488381.0

     0.050  100000.000      30.000       1.000       0.020     30
 1454209.7    259058.4   1195151.2

     0.050  100000.000      30.000       2.000       0.020     15
 1131670.8    185709.1    945961.7

     0.050  100000.000      30.000       3.000       0.020     10
  986765.4    153628.5    833136.8

     0.050  100000.000      30.000       5.000       0.020      6
  839587.7    121726.7    717861.0

     0.050  100000.000      30.000       6.000       0.020      5
  795187.7    112143.4    683044.3

     0.050  100000.000      30.000      10.000       0.020      3
  690702.6     88458.2    602244.3
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```
      0.050  100000.000        30.000       15.000           0.020      2
   627667.2     69643.0      558024.1

      0.050  100000.000        30.000       30.000           0.020      1
   567028.9         0.0      567028.9

      0.050  100000.000        30.000        1.000           0.050     30
  2413326.9    559103.3     1854223.5

      0.050  100000.000        30.000        2.000           0.050     15
  1808373.1    401653.1     1406720.0

      0.050  100000.000        30.000        3.000           0.050     10
  1540156.1    332986.3     1207169.7

      0.050  100000.000        30.000        5.000           0.050      6
  1273034.9    265004.6     1008030.3

      0.050  100000.000        30.000        6.000           0.050      5
  1194381.7    244690.6      949691.0

      0.050  100000.000        30.000       10.000           0.050      3
  1016776.8    194811.6      821965.1

      0.050  100000.000        30.000       15.000           0.050      2
   921513.7    155265.8      766247.9

      0.050  100000.000        30.000       30.000           0.050      1
   887451.5         0.0      887451.5

      0.050 1000000.000        30.000        1.000           0.010     30
  3482865.8    521105.3     2961760.5

      0.050 1000000.000        30.000        2.000           0.010     15
  2800850.2    373271.0     2427579.2

      0.050 1000000.000        30.000        3.000           0.010     10
  2492496.0    308549.0     2183947.0

      0.050 1000000.000        30.000        5.000           0.010      6
  2176321.9    244093.0     1932228.9

      0.050 1000000.000        30.000        6.000           0.010      5
  2079843.4    224697.9     1855145.5

      0.050 1000000.000        30.000       10.000           0.010      3
  1848621.3    176672.4     1671948.8

      0.050 1000000.000        30.000       15.000           0.010      2
  1702820.6    138523.5     1564297.1

      0.050 1000000.000        30.000       30.000           0.010      1
  1536292.1         0.0     1536292.1

      0.050 1000000.000        30.000        1.000           0.020     30
  4574483.2    814915.7     3759567.5

      0.050 1000000.000        30.000        2.000           0.020     15
  3559878.1    584182.1     2975696.0
```

```
      0.050 1000000.000       30.000        3.000         0.020    10
  3104051.4    483266.6  2620784.8

      0.050 1000000.000       30.000        5.000         0.020     6
  2641077.3    382913.6  2258163.6

      0.050 1000000.000       30.000        6.000         0.020     5
  2501408.8    352767.6  2148641.2

      0.050 1000000.000       30.000       10.000         0.020     3
  2172731.6    278261.7  1894469.9

      0.050 1000000.000       30.000       15.000         0.020     2
  1974442.2    219075.0  1755367.1

      0.050 1000000.000       30.000       30.000         0.020     1
  1783693.6         0.0  1783693.6

      0.050 1000000.000       30.000        1.000         0.050    30
  7591562.2   1758762.1  5832800.0

      0.050 1000000.000       30.000        2.000         0.050    15
  5688569.2   1263473.5  4425095.6

      0.050 1000000.000       30.000        3.000         0.050    10
  4844843.4   1047469.7  3797373.6

      0.050 1000000.000       30.000        5.000         0.050     6
  4004564.8    833620.6  3170944.1

      0.050 1000000.000       30.000        6.000         0.050     5
  3757146.8    769719.4  2987427.3

      0.050 1000000.000       30.000       10.000         0.050     3
  3198457.9    612815.9  2585642.0

      0.050 1000000.000       30.000       15.000         0.050     2
  2898790.3    488417.0  2410373.3

      0.050 1000000.000       30.000       30.000         0.050     1
  2791641.5         0.0  2791641.5

      0.000       0.000        0.000        0.000         0.000     0
        0.0         0.0          0.0
```

TABLE 4

```
       RI           POPI          TT           TI           RPG        N
     CCOST          SCOST        FCOST


       0.060      10000.000       30.000        1.000        0.010     30
     329112.7       40005.0     289107.6

       0.060      10000.000       30.000        2.000        0.010     15
     267213.8       28928.8     238285.0

       0.060      10000.000       30.000        3.000        0.010     10
     239232.3       24140.5     215091.8

       0.060      10000.000       30.000        5.000        0.010      6
     210585.2       19463.0     191122.1

       0.060      10000.000       30.000        6.000        0.010      5
     201870.6       18087.2     183783.4

       0.060      10000.000       30.000       10.000        0.010      3
     181140.2       14770.9     166369.3

       0.060      10000.000       30.000       15.000        0.010      2
     168372.6       12143.5     156229.1

       0.060      10000.000       30.000       30.000        0.010      1
     155254.3           0.0     155254.3

       0.060      10000.000       30.000        1.000        0.020     30
     427025.5       62560.7     364464.7

       0.060      10000.000       30.000        2.000        0.020     15
     335294.3       45274.5     290019.7

       0.060      10000.000       30.000        3.000        0.020     10
     294114.1       37810.2     256303.8

       0.060      10000.000       30.000        5.000        0.020      6
     252395.1       30532.1     221863.0

       0.060      10000.000       30.000        6.000        0.020      5
     239866.1       28396.2     211469.8

       0.060      10000.000       30.000       10.000        0.020      3
     210684.9       23264.4     187420.5

       0.060      10000.000       30.000       15.000        0.020      2
     193664.3       19205.0     174459.3

       0.060      10000.000       30.000       30.000        0.020      1
     180256.2           0.0     180256.2

       0.060      10000.000       30.000        1.000        0.050     30
     694040.7      135019.5     559021.2

       0.060      10000.000       30.000        2.000        0.050     15
     523944.5       97920.2     426024.3

       0.060      10000.000       30.000        3.000        0.050     10
```

```
  448687.1     81952.8    366734.2

     0.060   10000.000      30.000        5.000        0.050      6
  374102.8     66469.7    307633.0

     0.060   10000.000      30.000        6.000        0.050      5
  352316.2     61959.0    290357.2

     0.060   10000.000      30.000       10.000        0.050      3
  304010.3     51235.2    252775.1

     0.060   10000.000      30.000       15.000        0.050      2
  279861.9     42816.6    237045.3

     0.060   10000.000      30.000       30.000        0.050      1
  282117.2         0.0    282117.2

     0.060  100000.000      30.000        1.000        0.010     30
 1035284.5    125843.2    909441.2

     0.060  100000.000      30.000        2.000        0.010     15
  840570.1     91000.8    749569.3

     0.060  100000.000      30.000        3.000        0.010     10
  752549.2     75938.4    676610.7

     0.060  100000.000      30.000        5.000        0.010      6
  662434.4     61224.6    601209.8

     0.060  100000.000      30.000        6.000        0.010      5
  635021.2     56896.6    578124.6

     0.060  100000.000      30.000       10.000        0.010      3
  569809.7     46464.6    523345.1

     0.060  100000.000      30.000       15.000        0.010      2
  529647.0     38199.7    491447.3

     0.060  100000.000      30.000       30.000        0.010      1
  488381.0         0.0    488381.0

     0.060  100000.000      30.000        1.000        0.020     30
 1343287.1    196796.4   1146490.6

     0.060  100000.000      30.000        2.000        0.020     15
 1054729.8    142419.4    912310.3

     0.060  100000.000      30.000        3.000        0.020     10
  925189.8    118939.0    806250.8

     0.060  100000.000      30.000        5.000        0.020      6
  793955.1     96044.3    697910.8

     0.060  100000.000      30.000        6.000        0.020      5
  754542.9     89325.6    665217.2

     0.060  100000.000      30.000       10.000        0.020      3
  662748.0     73182.4    589565.5
```

```
      0.060   100000.000        30.000        15.000          0.020      2
   609206.7      60412.8      548793.9

      0.060   100000.000        30.000        30.000          0.020      1
   567028.9          0.0      567028.9

      0.060   100000.000        30.000         1.000          0.050     30
  2183232.5     424728.7     1758503.7

      0.060   100000.000        30.000         2.000          0.050     15
  1648163.7     308025.9     1340137.8

      0.060   100000.000        30.000         3.000          0.050     10
  1411427.5     257797.7     1153629.7

      0.060   100000.000        30.000         5.000          0.050      6
  1176809.0     209092.9      967716.0

      0.060   100000.000        30.000         6.000          0.050      5
  1108275.4     194903.6      913371.8

      0.060   100000.000        30.000        10.000          0.050      3
   956320.3     161169.8      795150.5

      0.060   100000.000        30.000        15.000          0.050      2
   880357.1     134687.5      745669.6

      0.060   100000.000        30.000        30.000          0.050      1
   887451.5          0.0      887451.5

      0.060  1000000.000        30.000         1.000          0.010     30
  3256677.2     395863.1     2860814.1

      0.060  1000000.000        30.000         2.000          0.010     15
  2644167.5     286259.8     2357907.6

      0.060  1000000.000        30.000         3.000          0.010     10
  2367281.4     238878.4     2128403.0

      0.060  1000000.000        30.000         5.000          0.010      6
  2083809.0     192593.3     1891215.7

      0.060  1000000.000        30.000         6.000          0.010      5
  1997575.7     178978.7     1818596.9

      0.060  1000000.000        30.000        10.000          0.010      3
  1792441.1     146163.0     1646278.1

      0.060  1000000.000        30.000        15.000          0.010      2
  1666102.0     120164.1     1545937.8

      0.060  1000000.000        30.000        30.000          0.010      1
  1536292.1          0.0     1536292.1

      0.060  1000000.000        30.000         1.000          0.020     30
  4225555.9     619059.3     3606496.6

      0.060  1000000.000        30.000         2.000          0.020     15
  3317846.1     448006.5     2869839.5
```

```
     0.060 1000000.000        30.000         3.000         0.020    10
 2910354.3    374144.6     2536209.7

     0.060 1000000.000        30.000         5.000         0.020     6
 2497531.5    302125.0     2195406.5

     0.060 1000000.000        30.000         6.000         0.020     5
 2373553.0    280990.1     2092562.8

     0.060 1000000.000        30.000        10.000         0.020     3
 2084795.4    230208.9     1854586.5

     0.060 1000000.000        30.000        15.000         0.020     2
 1916371.6    190039.7     1726331.8

     0.060 1000000.000        30.000        30.000         0.020     1
 1783693.6         0.0     1783693.6

     0.060 1000000.000        30.000         1.000         0.050    30
 6867758.1   1336062.2     5531695.9

     0.060 1000000.000        30.000         2.000         0.050    15
 5184601.3    968952.1     4215649.2

     0.060 1000000.000        30.000         3.000         0.050    10
 4439904.1    810950.2     3628953.9

     0.060 1000000.000        30.000         5.000         0.050     6
 3701868.4    657740.1     3044128.3

     0.060 1000000.000        30.000         6.000         0.050     5
 3486283.5    613105.0     2873178.5

     0.060 1000000.000        30.000        10.000         0.050     3
 3008280.9    506989.2     2501291.7

     0.060 1000000.000        30.000        15.000         0.050     2
 2769324.7    423684.2     2345640.5

     0.060 1000000.000        30.000        30.000         0.050     1
 2791641.5         0.0     2791641.5

     0.000       0.000         0.000         0.000         0.000     0
       0.0         0.0           0.0
```

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Memorandum

TO : F. M. Middleton **DATE**: May 6, 1971

FROM : Robert Smith and Richard Eilers

SUBJECT: Progress Towards Finding the Least Cost Solution for Consolidation of Treatment Plants by Means of Pipelines Where Three or More Plants are Involved

A linear programming technique has been developed for solving the problem of how to consolidate three or more treatment plants to minimize the total cost for treatment and shipment. Two methods have been worked out. One uses the Simplex algorithm for linear programming and the second uses the transhipment modification of the transportation algorithm.

To show how the two methods can be used consider the simple example shown diagrammatically in Figure 1 involving three point sources of wastewater. Each point source can ship to one of the other two sources or the decision can be made to treat the wastewater at the point source. A hypothetical treatment plant is located at each point source. Each treatment plant discharges to the environment and this is indicated by the ground symbol. Magnitudes of the point sources, in millions of gallons per day are shown in Figure 1 with the cost of shipment by pipeline and the cost of treatment given in cents per thousand gallons. The total cost of the system is then equal to the product of the flow (mgd) and the cost of treatment or shipment (cents/Kgal) summed over all chords.

In this kind of analysis the point sources and the treatment plants are called nodes while the pipelines connecting the nodes are called chords. The cost of treatment can be assigned to either the chord connecting the point source with the treatment plant or the chord connecting the treatment plant with the environment.

Each point source is assigned an identifying number; in this example, 1, 2, and 3. The flows, in mgd, in the chords are called $X_{m,n}$ where m is the number of the node from which flow originates and n is the number of the node receiving the flow.

The example problem shown in Figure 1 can be solved using the Simplex algorithm by first writing mass balances around each of the point sources. For example, around node 1 the mass balance equation is written as follows:

$$4 = X_{1,1} + X_{1,2} - X_{2,1} + X_{1,3} - X_{3,1}$$

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The beginning Simplex tableau consists of three constraint equations representing the mass balances written around each of the three point sources. Since these three constraints are equalities instead of inequalities, we must introduce three artificial variables for the first tableau. The costs for the artificial variables are set at 10^6 cents/Kgal to make sure that the artificial variables are forced out of the final solution. The beginning tableau for the Simplex algorithm to solve Example I is shown in Figure 2.

A computer program has been developed to solve the Simplex algorithm and a description of the program is shown in a memorandum from R. Smith and Ella Hall to F. M. Middleton, dated March 24, 1971.

The solution to Example I using the Simplex algorithm is shown in Figure 3. The integer shown as (N) is an identification number. The variables in the original tableau are numbered consecutively starting with the non-basic variables followed by the basic variables. For example, in Figure 2 $X_{1,1}$ is variable number one, $X_{3,2}$ is variable number nine and the artificial variables are numbered 10, 11, and 12. In the final tableau representing the optimum solution variables 4, 8, and 3 appear. The least cost solution is, therefore, to ship 4 mgd to point source number 2 and then to ship 9 mgd to point source number 3 where all fifteen mgd will be treated. The cost of the optimum solution is 193(mgd) (cents/Kgal) or $1930 per day.

The same problem, Example I, can be solved using the transhipment modification of the transportation algorithm.

The transportation algorithm is a modification of the linear programming method which is used to find the least cost for shipping material from a given number of sources to a given number of destinations. The cost of shipment from each source to each destination is given. In many problems including the consolidation of treatment plants we must consider the possibility of shipping to any destination by way of any other source or any other destination.

The transhipment problem was solved formally by Orden[1] and a discussion of the method is given by Hadley[2]. In the transhipment problem all sources and destinations are considered to act interchangeably as sources and destinations. The shortages and surpluses which make up the rim requirements in the transportation problem must be modified for the transhipment tableau. For example, the first step is to sum all of the source surpluses. The surpluses which appear in the last column of the tableau are found by adding the source surplus to the sum of all source surpluses for each source. The surplus for each destination is set equal to zero plus the sum of all surpluses.

For BA 512 Quantitative Business Methods
Prof. Robert J. Thierauf

USE OF SIMPLEX ALGORITHM AND TRANSPORTATION ALGORITHM FOR FINDING THE LEAST COST SOLUTION FOR CONSOLIDATION OF TREATMENT PLANTS BY MEANS OF PIPELINES

By R. Smith

A linear programming technique has been developed for solving the problem of how to consolidate three or more treatment plants to minimize the total cost for treatment and shipment. Two methods have been worked out. One uses the Simplex algorithm for linear programming and the second uses the transhipment modification of the transportation algorithm.

To show how the two methods can be used consider the simple example shown diagrammatically in Figure 1 involving three point sources of wastewater. Each point source can ship to one of the other two sources or the decision can be made to treat the wastewater at the point source. A hypothetical treatment plant is located at each point source. Each treatment plant discharges to the environment and this is indicated by the grou l symbol. Magnitudes of the point sources, in millions of gallons per day are shown in Figure 1 in cents per thousand gallons. The total cost of the system is then equal to the product of the flow (mgd) and the cost of treatment or shipment (cents/Kgal) summed over all chords.

In this kind of analysis the point sources and the treatment plants are called nodes while the pipelines connecting the nodes are called chords. The cost of treatment can be assigned to either the chord connecting the point source with the treatment plant or the chord connecting the treatment plant with the environment.

Each point source is assigned an identifying number; in this example, 1, 2, and 3. The flows, in mgd, in the chords are called $X_{m,n}$ where m is the number of the node from which flow originates and n is the number of the node receiving the flow.

The example problem shown in Figure 1 can be solved using the Simplex algorithm by first writing mass balances around each of the point sources. For example, around node 1 the mass balance equation is written as follows:

$$4 = X_{1,1} + X_{1,2} - X_{2,1} + X_{1,3} - X_{3,1}$$

FLOW DIAGRAM FOR EXAMPLE I

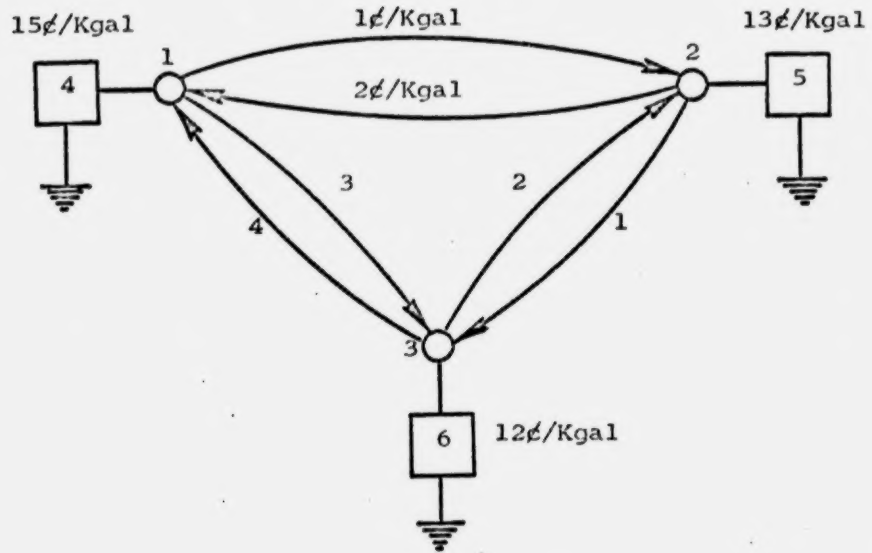
15¢/Kgal
1¢/Kgal
13¢/Kgal
1
2
4
2¢/Kgal
5
3
2
4
1
3
6
12¢/Kgal

Figure 1

The begining Simplex tableau consists of three constraint equations representing the mass balances written around each of the three point sources. Since these three constraints are equalities instead of inequalities, we must introduce three artificial variables for the first tableau. The costs for the artificial variables are set at 10^6 cents/Kgal to make sure that the artificial variables are forced out of the final solution. The beginning tableau for the Simplex algorithm to solve Example I is shown in Figure 2.

The solution to Example I using the Simplex algorithm is shown in Figure 3. The integer shown as (N) is an identification number. The variables in the original tableau are numbered consecutively starting with the non-basic variables followed by the basic variables. For example, in Figure 2 $X_{1,1}$ is variable number one, $X_{3,2}$ is variable number nine and the artificial variables are numbered 10, 11, and 12. In the final tableau representing the optimum solution variables 4, 8, and 3 appear. The least cost solution is, therefore, to ship 4 mgd to point source number 2 and then to ship 9 mgd to point source number 3 where all fifteen mgd will be treated. The cost of the optimum solution is 193 (mgd) (cents/Kgal) or $1930 per day.

The same problem, Example I, can be solved using the transhipment modification of the transportation algorithm.

The transportation algorithm is a modification of the linear programming method which is used to find the least cost for shipping material from a given number of sources to a given number of destinations. The cost of shipment from each source to each destination is given. In many problems including the consolidation of treatment plants we must consider the possibility of shipping to any destination by way of any other source or any other destination.

The transhipment problem was solved formally by Orden[1] and a discussion of the method is given by Hadley[2]. In the transhipment problem all sources and destinations are considered to act interchangeably as sources and destinations. The shortages and surpluses which make up the rim requirements in the transportation problem must be modified for the transhipment tableau. For example, the first step is to sum all of the source surpluses. The surpluses which appear in the last column of the tableau are found by adding the source surplus to the sum of all source surpluses for each source. The surplus for each destination is set equal to zero plus the sum of all surpluses.

EXAMPLE I: LEAST COST SOLUTION FOR CONSOLIDATION OF THREE SOURCES

1. Simplex Method

CB	B	$X_{1,1}$	$X_{2,2}$	$X_{3,3}$	$X_{1,2}$	$X_{2,1}$	$X_{1,3}$	$X_{3,1}$	$X_{2,3}$	$X_{3,2}$	
10^6	4	1			1	-1	1	-1			
10^6	5		1		-1	1			1	-1	A
10^6	6			1			-1	1	-1	1	
		15	13	12	1	2	3	4	1	2	CNB

2. Transhipment Modification of Transportation Method

Destinations

Sources	1	2	3	G	
1	0	1	3	15	19
2	2	0	1	13	20
3	4	2	0	12	21
G	M*	M	M	0	15
	15	15	15	30	75

* $M=10^6$

Figure 2

```
   9 NON-BASIC VARIABLES
   3 BASIC VARIABLES
                                                         A MATRIX            MINIMIZE

 1.0  0.0  0.0  1.0 -1.0  1.0 -1.0  0.0  0.0
 0.0  1.0  0.0 -1.0  1.0  0.0  0.0  1.0 -1.0
 0.0  0.0  1.0  0.0  0.0 -1.0  1.0 -1.0  1.0
                                                         CNB VECTOR   - COST OF NON-BASIC VARIABLES

15.0 13.0 12.0  1.0  2.0  3.0  4.0  1.0  2.0
                                                         B VECTOR  -REQUIREMENTS VECTOR

   4.0000     5.0000     6.0000
                                                         CB VECTOR   - COST OF BASIC VARIABLES

 1000000.  1000000.  1000000.

       N         B             CB
      10     0.4000E 01     0.1000E 07
      11     0.5000E 01     0.1000E 07
       3     0.6000E 01     0.1200E 02

       N         B             CB
      10     0.4000E 01     0.1000E 07
       8     0.5000E 01     0.1000E 01
       3     0.1100E 02     0.1200E 02

       N         B             CB
       4     0.4000E 01     0.1000E 01
       8     0.9000E 01     0.1000E 01
       3     0.1500E 02     0.1200E 02

   OPTIMUM COST=          193.00
```

Figure 3

The shortages which appear in the last row of the tableau are found by adding the destination shortage to the sum of the source surpluses for each destination and adding zero to the sum of the source surpluses for each source. The beginning transportation tableau for the example shown in Figure 1 is given in Figure 2.

The transportation algorithm requires that the sum of all the surpluses must equal the sum of all the shortages. To satisfy this requirement a single destination representing the environment was hypothesized. The cost of treatment was associated with the chord from each treatment plant to the environment or ground. The cost associated with the chord from the point source to the treatment plant was taken as zero. A large cost of 10^6 cents/Kgal was used to suppress shipment from ground to the sources.

A computer program which uses only integers was obtained from IBM to solve the transportation algorithm. The solution to the first example problem using this program is shown in Figure 4.

The final tableau for the transportation algorithm shown in Figure 4 is interpreted as follows. Source No. 1 ships 4 mgd to source No. 2 where it is combined with the 5 mgd from source No. 2 and treated at a cost of 13 cents/Kgal. The 6 mgd originating at source No. 3 is treated at source No. 3. The total cost is the product of mgd and cents/Kgal summed over all chords including shipment and treatment. The total cost is 193 (mgd)(cents/Kgal) or $1930 per day. In this simple example, we have found two different optimum solutions both giving the same minimum cost.

This is not uncommon and if we reduce the cost of treatment at source two to 12.99 cents/Kgal, the Simplex method willgive the same solution as the transportation algorithm. This is shown in Figure 5.

The methods described above are deficient in that they do not take account of economy of scale for both shipment and treatment. Various methods are available to correct this deficiency but they all involve much more complicated solutions than the ones given above. When the solution set is convex as it is with linear constraints and the objective function is separable, the cost function can be approximated by a piecewise linear function. This requires a piecewise linear function in terms of cents/Kgal for each treatment plant and each pipeline. The number of variables is multiplied by the number of segments selected for the cost functions and additional constraints are needed. This makes a very difficult problem out of a rather simple situation. Gradient methods can also be used. The method of feasible directions developed by Zoutendijk in an iterative technique which makes use of linear programming and takes the unit costs as those applicable to the last iteration. I suspect that this method has the most promise.

```
TRANSPORTATION PROBLEM INPUT


SURPLUSES

 MA 1=   19
 MA 2=   20
 MA 3=   21
 MA 4=   15


SHORTAGES

 MB 1=   15
 MB 2=   15
 MB 3=   15
 MB 4=   30


UNIT SHIPPING COST MATRIX


              DESTINATIONS

               1     2     3     4

SOURCES   1    0     1     3    15
          2    2     0     1    13
          3    4     2     0    12
          432000320003200O       0
```

```
TRANSPORTATION PROBLEM OPTIMAL SOLUTION


MATRIX OF SHIPPING QUANTITIES


                DESTINATIONS

             1     2     3     4

SOURCES   1  15    4     0    .0
          2  0    11     0     9
          3  0     0    15     6
          4  0     0     0    15

TOTAL SHIPPING COST

          193
```

Figure 4

```
        9 NON-BASIC VARIABLES
        3 BASIC VARIABLES

                                                              A MATRIX
   1.0  0.0  0.0  1.0 -1.0  1.0 -1.0  0.0  0.0
   0.0  1.0  0.0 -1.0  1.0  0.0  0.0  1.0 -1.0
   0.0  0.0  1.0  0.0  0.0 -1.0  1.0 -1.0  1.0
                                                              CNB VECTOR   - COST OF NON-BASIC VARIABLES
  15.0 12.9 12.0  1.0  2.0  3.0  4.0  1.0  2.0
                                                              B VECTOR  -REQUIREMENTS VECTOR
     4.0000      5.0000      6.0000
                                                              CB VECTOR   - COST OF BASIC VARIABLES
  1000000.  1000000.  1000000.

        N        B              CB
       10    0.4000E 01    0.1000E 07
       11    0.5000E 01    0.1000E 07
        3    0.6000E 01    0.1200E 02

        N        B              CB
       10    0.4000E 01    0.1000E 07
        8    0.5000E 01    0.1000E 01
        3    0.1100E 02    0.1200E 02

        N        B              CB
        4    0.4000E 01    0.1000E 01
        8    0.9000E 01    0.1000E 01
        3    0.1500E 02    0.1200E 02

        N        B              CB
        4    0.4000E 01    0.1000E 01
        2    0.9000E 01    0.1299E 02
        3    0.6000E 01    0.1200E 02

   OPTIMUM COST=          192.91
```

Figure 5

Another problem associated with non-linear cost functions is that the objective function expressed as a sum of terms involving the product of mgd and cents/Kgal is concave because the unit cost decreases as the amount of water treated or shipped increases. When the problem is to minimize a concave function on a convex set, there can be no assurance that the local minimum is a global minimum.

The fundamental importance of this limitation can be seen by starting with the initial feasible solution providing that all point sources treat the wastewater at the source. Using gradient methods we must then consider the cost advantage of shipping a small amount of water from one source to another. Since the cost of shipment increases sharply as the amount shipped is reduced, the decision made by the gradient method will always be not to ship. Thus, we have achieved a local optimum but not the global optimum. The only alternative is to assume another initial solution and to apply the gradient method at the new point. Again we will achieve a local optimum with no assurance that we have reached a global optimum.

The simple linear programming approach might be used in a cut and try procedure. For example, if the cost of shipment is set equal to a minimum by assuming that the unit cost of shipment is equal to that corresponding to shipping all sources through each pipe, the problem will be biased in favor of shipment. If, when this assumption is made, the solution is still to treat at the sources, we know that the true solution will be to treat at the sources. If with this assumption the optimum solution involves some shipment, then the costs can be adjusted to match the amounts shipped and treated. The problem can be worked iteratively adjusting the unit costs at each iteration. This method has been used by some workers but the procedure is not guaranteed to arrive at the true optimum. More work is needed to clarify this procedure to be assured that the true local optimum is being achieved.

REFERENCES

1. A. Orden, "The Transhipment Problem," Management Science, 2, 3, pp. 276-285, 1956.
2. G. Hadley, Linear Programming, Addison-Wesley Publishing Company, June 1963.